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FEASIBILITY STUDY FOR SIMULATION OF AN AIRPORT TOWER CONTROL ENVIRONMENT

Dr. Helen W. Hamilton

FEBRUARY 1978

FINAL REPORT

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NOTICE

METRIC CONVERSION FACTORS

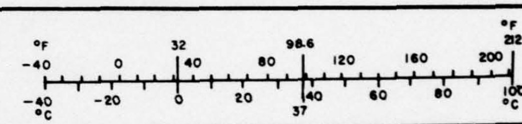
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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16. Abstract

The feasibility and desirability of developing an airport tower control simulation training facility at the FAA Academy was investigated. Training program needs were assessed, and the state-of-the-art in simulation technology was surveyed. Several large-scale airport tower and ship's bridge simulators are described and evaluated from an operational and engineering viewpoint; also, a number of flight simulators and image generation and projection systems are considered with regard to the applicability of the concepts to the FAA training requirements. Computer-generated image systems versus other imaging technologies are discussed with reference to realism requirements, capability for efficient generation of instructional materials, and for objective student evaluation. The large number of visual-scene simulation facilities presently in use or under contract development for a wide variety of uses indicates that a tower control application is entirely feasible.

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PREFACE

The work in this report could not have been completed without the participation of Theodore W. Rundall and Floyd B. Woodson of the Human Engineering Branch at NAFEC. Mr. Rundall, air traffic control specialist, provided the controller's viewpoint for the operational evaluations of the various systems surveyed, and Mr. Woodson contributed his expertise for the engineering evaluations. Their observations and comments are incorporated into the analyses, conclusions, and recommendations of this report.

A special expression of appreciation is due to engineers William Dunn and Gerard Spanier of the Human Engineering Branch, NAFEC, who provided extensive and expert knowledge in the field of display and projection devices. The education and information they provided was essential to the success of this project. Controllers Steven Karovic and Richard Rood, also of the Human Engineering Branch, and Maxwell Peck and Charles Davis of the FAA Academy, Air Traffic Branch, provided valuable advice and information based on their experience in aviation, air traffic control, and training. Their contribution is greatly appreciated.

The author would also like to express her appreciation to the many marketing representatives, engineers, and laboratory personnel in industry and in the military who provided information and material for this report, conducted laboratory demonstrations for the project members, and who patiently engaged in lengthy discussions having to do with the potential for modification of their systems to satisfy the specialized requirements of an airport visual-scene simulation.

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INTRODUCTION

OBJECTIVES.

The objectives of this study are as follows:

1. Determine the feasibility of simulating an airport tower control environment,

2. Recommend state-of-the-art simulation systems which satisfy Federal Aviation Administration (FAA) tower control training requirements, and

3. Provide functional air traffic control (ATC) tower simulation requirements as required.

BACKGROUND.

There has been concern for some time on the part of the FAA to improve its Air Traffic Controller Training Program. As a result of investigations and evaluations by the Corson Committee (reference 1), the Coleman report (reference 2), Congressional Hearings Committee Reports (reference 3 and 4), and the Institute for Defense Analysis (IDA) report (reference 5), specific deficiencies have been identified. The Office of Personnel and Training, in concert with the Air Traffic Service, embarked on an effort to develop a revised terminal/enroute training program which would address these deficiencies. To support this effort, research and development actions were requested from the Associate Administrator for Engineering and Development, resulting in the establishment of the Engineering and Development Working Group on Air Traffic Control Specialists (ATCS) Training. The working group, composed of representatives from Systems Research and Development Service (SRDS), National Aviation Facilities Experimental Center (NAFEC), Office of Aviation Medicine, Office of Personnel and Training, and Air Traffic Service chaired by the Office of Systems Engineering Management which defined the engineering and development support required for the overall FAA program of upgrading the selection, training, and performance evaluation of ATCS in the Engineering and Development Program Plan (Report No. FAA-ED-21-3).

One aspect of the training program identified by the IDA report as vital to improved training efficiency and cost economy is the need for inclusion, as soon as possible, of simulation capabilities in the training program. This recommendation was reiterated in the formal report of a review of FAA training programs, conducted by the Assistant Secretary of the Air Force, Manpower and Reserve Affairs, at the request of the Office of the Administrator, FAA (reference 6). In response to this need, and as part of the overall effort requested of NAFEC by SRDS, the Human Engineering Branch at NAFEC was requested to explore the technical feasibility of developing a training device which simulates an airport control tower environment. The results of the study, under project 216-102-100 of NPD-21-279, ATCS Personnel Support Program, are presented here.

APPROACH

TRAINING REQUIREMENTS ASSESSMENT.

To establish a basis for assessing the requirements of the FAA Academy for a tower simulator, interviews were conducted with specialists in the Terminal Development/Revision Section, Air Traffic Branch of the Academy, and a tour was made of the classrooms and laboratory facilities at the Academy. Contact with Academy personnel has been maintained throughout this study. Several tower facilities were visited and on-the-job training discussed with supervisors. Included in documents reviewed are the National Air Traffic Training Program, Terminal Instructional Program Guide, TP 12-0-1 (reference 7), and the reports on terminal controller job analyses performed by System Development Corporation (references 8, 9, 10, 11). In addition, a number of discussions were held with air traffic controllers at NAFEC for their input concerning features considered essential in a tower simulation device.

SIMULATION TECHNOLOGY SURVEY.

Progress of the development of the airport tower simulator by AAI Corporation of Cockeysville, Maryland, for deployment by the United States Air Force (USAF) at Keesler Air Force Base (AFB) was monitored as requested by SRDS. Training devices for tower control training planned or in present use by other branches of the military and by foreign countries were investigated. Contact was made with marketing representatives, engineers, and laboratory researchers in industry and government agencies in order to survey the state-of-the-art in electronic display techniques, in image generation technology, in large screen display systems, and to determine the expected present and long-range capabilities of these systems.

FINDINGS

TRAINING REQUIREMENTS ASSESSMENTS SUMMARY.

The survey of the training requirements was concerned with three areas: organizational constraints, training task requirements, and personnel needs. Interviews with Academy training specialists and with personnel of the Office of Personnel and Training provided much information, as did the training program guides and reference materials. However, many of the requirements are unspecified at present, and further study will be required in order to define them.

The organizational needs are most clearly spelled out. According to the information obtained in the survey, there will be some modification to the present structure of the training program schedule as outlined in the Instructional Program Guide for Terminal Control. A revised program for controller training was begun at the Academy in January 1976. It consists of six phases, the first

and last of which are conducted at the hiring facility. Phases II to V are conducted at the Academy over a period of approximately 15 weeks. The course content and approximate length of training for each phase are as follows:

Phase I:	Indoctrination	2 weeks
Phase II:	Fundamentals of Air Traffic Control	6 weeks
Phase III:	Control Tower Operations	3 weeks
Phase IV:	Nonradar Air Traffic Control	4 weeks
Phase V:	Radar Air Traffic Control	2 weeks
Phase VI:	Facility Qualification Classroom	17 weeks
	On-the-Job	17 weeks

According to the Instructional Program Guide, Phase III, Control Tower Operation is to be conducted in classroom and laboratory environments using lesson plans, visual aids, and simulated problems. The objective of this phase is to "... prepare the specialist to demonstrate, through criterion tests and simulation, a comprehensive knowledge of the flight data/clearance delivery position, ground control position, and the local control/BRITE radar position."

The present Academy tower training capabilities provide practical experience on the flight data (FD) and clearance delivery (CD) positions. Practical experience on ground control (GC) and local control (LC) is obtained on the job at the home facility. A staff study conducted by Air Traffic Branch, Terminal Development/Revision Section at the Academy, investigated various methods of LC and GC simulation which could be implemented at the Academy as an interim measure (reference 12). Methods considered were (a) the "vertical board," which consists of an upright display board depicting an airport layout and using magnetic model airplanes, and (b) the "horizontal display," a control tower laboratory which consists of an airport layout on a large table top and scale model aircraft on control rods. Consideration is currently being given to the introduction of a horizontal display facility at the FAA Academy as an interim training device to provide the practical portion of training under Phase III, Control Tower Operations. This new system and a forthcoming new radar training facility will result in adjustments to the training schedule shown above.

Other aspects of organizational requirements have to do with student load and physical space. The terminal training schedule calls for an input of 882 new recruits per year in seven or eight entrance groups of 126 students each. Each group of 126 is handled in 7 classes of 18 students each. Present teaching arrangements consist of two shifts of three or four classes, each running concurrently. Classroom facilities for practical training on the FD position are such that, at any one time, 6 students perform while 12 watch. The use of the horizontal display would enlist the services of nonacting students as support pilots, the ratio of support students to active students depending on the number of aircraft involved and the complexity of the problem. It is generally considered that some amount of operations learning takes place for students acting in support roles, though a learning plateau occurs relatively early.

<u>Training task requirements</u> specify the knowledges and skill to be learned at the Academy or on the job later. Most of these are outlined in the Instruction

Guide; however, since there is presently no tower training laboratory, there are no examples of dynamic air traffic problems available to be used as a basis for requirements for specifying the capabilities which a simulator should have. Questions such as the number of aircraft and/or land vehicles which the system should be able to display simultaneously is one example of the type of information needed. Requirements of this nature were addressed at a very general level in the interviews and during the subsequent discussions (reference 13) with Academy personnel. The following list itemizes some of the opinions expressed.

1. Potential for aircraft recognition and identification,

2. About 10 to 30 simultaneous targets including aircraft and ground vehicles,

3. Provision for day and night conditions,

4. Provision for wind conditions, and

5. Capability for evaluation of a four-person tower team.

Personnel requirements include the needs of both the developmental ATCS and the instructor. The system should provide the capability for early screening and routine testing of the student and the use of objective measurements. Not directly expressed in the interviews, but of very great importance, is that a system should provide the capability for creating the instructional materials efficiently, in as short a time as possible, and with a minimum of technical background required of the user.

SIMULATION TECHNOLOGY SURVEY SUMMARY.

Visual scene simulation systems in the past have used a variety of techniques for image generation, display, and projection. Traditionally, scale models, model boards, or pictures have been used in conjunction with optics and/or a television camera focused on the model for generating the picture to be displayed. Complex servo mechanisms, as a component of the model or the camera system, are generally required in order to produce motion effects and to accommodate dynamic interaction between the user and the simulated environment. The simultaneous display of more than two or three interactive models has not been accomplished. Model boards are costly to illuminate and require large areas for use and storage. Models and model board systems generally are not used where a number of gaming areas are required.

Photographic techniques have been employed to provide a visual panoramic effect for flight and highway driving simulators. However, dynamic interaction between the student's controls and other independently moving aircraft or vehicles in the scene is difficult, if not impossible to accomplish. Generally, realism of the displayed scene is very good.

Computer-generated image (CGI) systems have developed rapidly over the past decade. Realism and capability have improved greatly. Unlike models, model boards, and photographic systems, CGI achieves complex interaction between

the user's control system and numerous other aircraft, ships, etc., in the displayed scene. Storage of visual environments is on disk or tape, and user software packages provide for easy modification or construction of new environments. Various display and projection configurations make possible a range of simulator capabilities from that of a single monitor system to the highly sophisticated ship's bridge facility to be described later.

These various image generation techniques present pseudo-three-dimensional scenes, in that cues of depth, such as juxtaposition, perspective linearity, and aerial haze may be present, but binocular cues of eye accommodation and convergence are absent. Special imaging optics can provide these latter cues to some extent. True depth perspective is being investigated with stereoscopic projected display systems and with holographic techniques, though the latter can be considered in an embryonic stage for large-scale, dynamic presentations.

Of the many simulator-training systems in operation, only two are used for airport tower control training (the Canadian and the United States Navy (USN) facilities). The survey and this report concern the appraisal of technologies and components, as well as other types of simulator-training which show potential for application to a tower-trainer development. This includes types of image-generation systems, projection devices, and ship's bridge and flight simulator facilities. The following is a listing and very brief description of each system. Complete descriptions and discussions are given in the appendices.

COMPUTER-GENERATED IMAGE SYSTEMS (APPENDIX A). Computer-generated image data bases are created from maps and geographical information of the area of interest. These data are supplied to the image-generator for display, either in a raster-scan or a random-write format. Raster-scan produces both day and night visual scenes. Random-write typically has produced only night or dusk scenes; however, a recent development (VITAL IV) is claimed to achieve dawn, day, dusk, and night effects. This is of particular interest, since the costs of CGI raster-scan systems are considerably greater than the random-write systems. The development is also claimed to have solved what has been a problem in the past--the achievement of both high-resolution and high-scene detail in a single system. Further investigation should be made of this CGI development for its capability to satisfy the tower-simulation requirements, specifically the simultaneous presentation of a large number of dynamically controllable targets.

PROJECTION DEVICES (APPENDIX B). A stereoscopic visual scene presentation system has been demonstrated in both a direct-view and projected-image configuration. To obtain the depth effect the viewer wears electronically controlled glasses having special ceramic lenses. Though not cumbersome, the glasses are costly and fragile. A recent development makes it possible to position the ceramic lens on the projector itself, thus reducing initial and operating costs at least as far as the lenses are concerned. In this version, the viewer needs only regulation Polaroid glasses to achieve the stereoscopic effect. Distance and motion parallax effects were very powerful in a demonstration depicting several sailboats underway as viewed across a bay area.

It is entirely feasible to consider a stereoscopic presentation of a view of airport traffic as seen from a tower window. The images could be projected on a large panoramic screen outside a full-scale tower cab, on an Advent screen or on smaller screens in a small-scale simulator configuration.

The stereoscopic image presentation has not been coupled with the CGI technique as far as is known at this time. It is technically simple to accomplish; however, and the funding of such a demonstration merits serious consideration.

Many of the large-scale projected image systems in the past have used the Eidophor projector. A new development (the light-valve) solves many of the maintenance problems associated with the Eidophor. An evaluation comparing the two types of projectors is given in appendix B, and in appendix D under the CAORF description.

CONTROL TOWER SIMULATORS (APPENDIX C). The listing of control tower simulators which follows shows a wide range in levels of realism and sophistication as well as conceptual approach to simulation training.

1. USAF Control Tower Simulator. This is a full-size simulator consisting of a tower cab surrounded by a cylindrical screen (210° horizontal field of view) on which an airport scene, and air and ground traffic are projected in color using computer-controlled slide and film-strip projectors. Instructors' and pseudopilots' positions are provided. The system is presently being installed at Keesler AFB.

2. USN Control Tower Trainer. In this operational facility, three windows of a tower cab mockup overlook a large horizontal display board on which are displayed a terminal area and traffic. Scale-model aircraft are manipulated by student controllers acting as pilots and receiving instructions via headsets.

3. DML Tower Demonstration Model. This is a CGI demonstration program which uses line drawings of aircraft projected on windows of a full-size tower cab. Full 360° field of view could be achieved.

4. GE Tower Simulation Concepts. These are several variations of a basic concept which uses large-screen projection, a cylindrical screen, full-size tower cab, and CGI technology for image generation in color of the airport as seen from the tower windows. The variations are in the configuration of the projection system.

5. Canadian Airport Trainer. This training and research simulation facility is being used for training of both terminal and airport tower operations. A plan-view of the airport area on a radar-type display uses symbols to represent various types of aircraft. Instructors' and pseudopilots' consoles are provided.

6. NAFEC Tower Simulation Model. This is a software program which presents on radar-type displays a plan view of an airport area and dynamically controllable air traffic. An out-the-window view of the airport can also be presented. Symbols with identification tags represent the aircraft.

It is clear that there is a wide variety of technical approaches which might be considered in the development of a tower training facility. Comparison is difficult, due to the diversity and range of levels of development of the simulations. The USN facility and the Canadian Trainer are the only functioning training facilities. The USAF trainer has had extensive delays due to problems with resolution of the projected aircraft images. The NAFEC and the DML models were demonstrated in breadboard form. The General Electric (GE) models are based on paper-concepts and developed equipment. The initial costs and operational and maintenance costs of a simulator based on any of these systems would depend on the extent to which one-of-a-kind and off-the-shelf items were used. The question of plan view versus visual-scene representation is taken up in the Analysis Section under considerations of how much realism is necessary in a training simulator.

SHIP'S BRIDGE SIMULATIONS (APPENDIX D). Visual-scene requirements for a bridge simulation are similar, in many ways, to tower requirements with the exception that a large number of dynamic images are required simultaneously in tower simulation. Two such systems were investigated:

1. CAORF Ship's Bridge Simulator. CAORF, an acronym for Computer Aided Operations Research Facility, is a highly sophisticated system using a full-scale bridge surrounded by a cylindrical screen (240° horizontal field-of-view) on which computer-generated scenes of various harbors and other ships are projected in color by Eidophor projectors. All daylight and night visual scenes, and virtually any type of weather condition can be displayed.

A special demonstration attempting to simulate aircraft movement was given in which a hydrofoil was programmed to appear at a distance, come toward, and pass by the bridge of "own-ship," much as an aircraft might pass a tower. The effect suggested that the CGI technique and large-screen projection could provide a powerfully realistic tower simulator.

2. Marine Safety International Ship's Bridge Simulator. This is a training facility for pilots of heavy tankers. It consists of a full-scale operational bridge surrounded by a cylindrical screen (140° field of view) on which harbor scenes are displayed using closed circuit TV, Eidophor projectors, and a model-board/camera-probe technique. There are problems in attempting to achieve large numbers of dynamically controllable images on the model-board system.

FLIGHT SIMULATIONS (APPENDIX E). The large numbers of flight simulators in use for training military and civilian pilots use virtually all types of visual-scene generation techniques. However, the most frequent new installations appear to use CGI technology. The following flight simulators have been selected because they have unique characteristics which differentiate them from the others and which might have application to tower simulation.

1. USAF Wide-Angle Visual Flight Simulator. An extremely wide field-of view is achieved (180° by 240°) by the juxtaposition of seven cathode ray tubes (CRT's) and imaging-optic lenses in a global array around an aircraft cockpit. On this large "screen" are displayed other aircraft, airports, etc., in monochrome.

The configuration of the USAF Wide-Angle Simulator suggests immediately a tower cab positioned inside a large global area on which aircraft images are projected. The major problem with this is the cost of production of the required optics, since the system, as it stands, probably is too small for simulating a tower cab environment. The Multiple Flight Simulator uses scale models in light boxes, a feature which presents a problem in generating large numbers of images simultaneously. Other types of projection could be considered to present CGI visual scenes on the dome screens.

2. Multiple Flight Simulator. This system consists of fighter aircraft cockpits inside domes which act as screens for the display of images representing each of the other aircraft. These images are generated by scale-model/camera techniques and projected onto the domes. Three cockpits are constructed, with another to be added in the future.

3. Instructor's Console for Flight Simulator. The item of interest in this system is the flight instructor's console, which consists of three television monitors which repeat the three perspective views presented to the pilot by large-screen projection techniques. The same CGI scene is viewed by pilot and instructor.

This configuration suggests a method of presenting an airport scene using CGI technology in a way which would eliminate the costs of large-screen projection systems, and yet achieve a wide enough field of view such that the controller would be required to scan his field of view much as a tower controller must do. Available lenses could be attached to the monitors to eliminate the effect of the vertical bar between the monitor screens.

OTHER TRAINING TECHNOLOGIES (APPENDIX F). The following two systems are currently being used in simulation training and should be given serious consideration for application to the FAA Academy training simulation facility development.

1. Picture System 2. This is an interactive computer-graphics system which presents dynamically moving two- and three-dimensional objects. It utilizes light-pen, stylus, or other data input devices. As used for flight training, the display shows a perspective view of a landing strip and the airport lighting.

Devices such as Picture System 2 have great potential for tower-control training. Dynamic air traffic exercises could be presented for student observation. At particular points in the exercise, questions requiring response could be displayed. Tutoring and scoring could be done by the computer programs. This would provide an excellent method to handle basic training. It would not provide, however, a realistic simulation environment for "hands-on" operations training.

2. Speech Understanding System (SUS) and Voice Generation Unit (VGU). Precision Approach Radar (PAR) controller training is being accomplished using SUS and VGU. Pilots' "voices" are generated during exercises as

needed. The controllers' statements are input and processed by the computer, and in turn, activate the movement of the target aircraft. The computer retains information during the course of the run in order to perform as an "instructor" later during a replay of the exercise. Evaluative comments are interjected by the "computer/instructor" at appropriate points during the replay. PAR uses a simplified controller vocabulary. However, an area-intercept controller-training program is under development wherein vocabularies similar in complexity to that of FAA controllers are being used and understood by the computer.

The SUS and VGU capability could be used with a stand-alone computer-graphics console to provide a high-level training device. It could also be considered as a supplemental training device for terminal or center facility training programs.

ANALYSIS

TRAINING.

The question of the feasibility of developing a simulation capability for training airport tower controllers at the FAA Academy can be answered simplistically. Yes, the state-of-the-art in simulation technology is such that a high-resolution, dynamic, real-time representation of an airport scene is possible. At a more meaningful level, the question is whether a simulation facility is practical and desirable. To look to other users of training simulators for evidence for making an informed decision appears fruitless. The USAF has selected full-scale, dynamic, computer-controlled, realistic simulation for tower control training, while the Naval Air Technical Training Center has found the horizontal display with manually manipulated aircraft to be adequate and fully satisfactory. The Canadian Air Traffic Training Office has chosen to use graphic CRT displays with symbols representing air and ground vehicles with a plan view of the airport area. England, Sweden, the Soviet Union, and Eurocontrol rely on on-the-job training to accomplish practical hands-on experience for tower training. The College of Air Traffic Services at Oxford Airport, England, which has trained students of 71 nationalities for overseas governments believes that "to train a good tower controller in the practical aspects of his work ... set him to work in a tower with a fairly low workload under the close and constant supervision of a qualified controller who can point out the correct way to do the job and the pitfalls into which a newcomer can fall" (reference 14). A unique and amusing method was used during World War II to train tower controllers at Hurn Airport in England. Bicycles with lights on were pedaled around the airfield simulating aircraft responding to tower commands. It is reported to have been "astonishingly realistic" (reference 15), but a facetious note is added that with today's aircraft speeds, mopeds would probably have to be used.

The advantages and disadvantages of the various systems have been pointed out in the previous section and are discussed more fully in the appendices. However, the basis for a firm decision on a recommendation for a training system from the point of view of practicality and desirability remains an elusive one.

It might be argued that since the Academy now has no tower training laboratory capability, then even a minimum level of simulation, such as the horizontal display board, would be satisfactory, inexpensive, and an immediate solution. However, it is tempting to envision the expected advantages to be obtained from a more sophisticated, realistic system. The question of how much realism is necessary cannot be answered on the basis of research data, since the required studies have not been done. Realism can be considered, however, from the point of view of its importance to various aspects of training, such as personnel selection, the training environment, transfer of training, and testing.

TRAINING SIMULATION AND REALISM.

PERSONNEL SELECTION. The attrition rate of terminal controllers over the developmental period is 38 percent. The major cost factors in training are caused by delays in screening and by the duration of training. A complete reduction in attrition losses could cut training costs by 22 percent. Since it costs approximately $37,000-60,000 to train a recruit to a full-performance terminal specialist, any cut in attrition losses would result in sizeable cost savings (reference 5).

An attempt has been made and is continuing (references 2 and 16) to identify controller skills and to develop valid selection tests. In the absence of such selection procedures, however, early screening during training becomes particularly important. Careful consideration should be given to the means by which such screening is accomplished. If a test using a radar-type display were to be used to make a pass-fail decision regarding a recruit's performance on tower procedures, there would have to be convincing evidence that the test was, in fact, valid and truly tested tower control skills. There is, at present, no such evidence. A test presented on a realistic simulator would have immediate face validity.

A training and screening device which provides realism has another important function in the area of personnel selection: it provides an opportunity for self-selection, by the recruit, at an early stage of training; that is, the earlier in his training that the student has the opportunity to actually carry out the job performance, the earlier he can find out whether or not he likes the type of work. For safety reasons, this can only be done in a simulated tower environment.

TRAINING ENVIRONMENT. The following quotation is taken from the IDA report: "Only that part of air traffic control that is a precise-sensory-motor skill requires high fidelity in simulation. On the other hand, if the critical skills are mostly in the area of decision making and communication, completeness rather than precise realism of the display on the scope will probably be most significant."

It is important to note that the authors were referring to radar simulation. Nevertheless, the point is an important one, since it raises the question of the extent to which tower control performance and decision-making involve critical skills based on learning to process specific visual information.

Consider an example of a routine clearance given to arrival aircraft, "November 3567, you are number four to land, follow the Trans World Boeing 707 on downwind." In a real-life situation, the controller would have to differentiate and identify the aircraft, and recall the flight characteristics of all the aircraft involved in the event in order to apply separation rules to the arriving aircraft. If the same event were portrayed on a radar-type display, identification would have to be given explicitly, either in a data tag or in tabular form, and flight characteristics would not be adequately represented. Important elements of the training task would be absent.

Another example which points out the inadequacy of a radar-type display to provide practice on certain aspects of tower control has to do with a particular departure regulation. The general rule regarding two departing aircraft using the same runway requires that the first aircraft must have crossed the end of the runway or made a heading change prior to a clearance being given to the second aircraft. However, the general rule can be modified if a category I is preceded by a category II aircraft and if distances can be estimated visually, such that the first aircraft need only be airborne and a 3,000-foot separation exists between the aircraft (reference 17, Sec. 11,12). If this event were portrayed on a radar-type display, all the visual cues, on the basis of which the controller would reach a decision regarding clearance for the second aircraft, would be different from those occurring in real life (or in a visual-scene simulation). Aircraft identification would be given, and distance would be estimated as on a flat map. The skills resulting in "good" performance may be quite different in the two situations.

Tower controllers refer to the "rapidity with which things happen" as characteristic of tower operations. Radar targets move more slowly and allow more time for decision-making. The aircraft being controlled on radar are all within approximately a 45° field of view. Tower targets cover a 360° field of view and move large distances (in terms of visual angle) in short periods of time. The two types of control may not only require different skills but also different types of individuals using a different set of visual cues.

TRANSFER OF TRAINING. The ideal training device should provide for the maximum amount of transfer from the practice situation to job performance. Two principles for maximizing the potential for positive transfer are: (1) maximize the similarity between the training environment and the performance environment, and (2) provide adequate experience with the original task. The advantages of similarity have been discussed in detail. With reference to the second principle, one author (reference 18), after an in-depth review of the training literature, found that the place where high levels of practice showed up to the greatest advantage on the job was during periods of stress or emergency. A training simulator should provide a high enough level of realism so that procedures which are well practiced will transfer directly to job situations, particularly in moments of emergency. On-the-job training alone may never provide the opportunity for practice on emergency procedures, and a nonrealistic simulation does not set the stage for direct transfer of learning.

TESTING. Two important functions of a training device which frequently are not given sufficient attention are the capability for development of training materials and the adaptability for objective evaluation of students. The advantage of using an interactive computer terminal and display for presenting exercises is that the training materials can be developed on-line at the display terminal.

Interactive computer programs can "lead" the instructor through the development process enabling fast, efficient construction of a large repertoire of air traffic problems. As for objective evaluation of performance, the computer-controlled image generation systems have the edge over other types of image generators in that the data are readily available for establishing norms and scoring procedures.

TRAINING SIMULATION TECHNOLOGY.

What can be gleaned from the state-of-the-art survey that indicates that current simulation technology can satisfy tower training requirements? Before this question can be answered, two important points must be emphasized: first, the airport tower simulation training requirements were not, and have not as yet, been specified, and second, there is in existance, as far as is known at this time, no operational visual-scene tower simulator which is available for "off-the-shelf" purpose, or even for demonstration. Therefore, considerations in response to the above question are based on certain assumptions regarding the Academy's tower training needs, research into the potential for various existing systems to accommodate the assumed requirements, and professional opinion with regard to critical features necessary to any training program using simulation.

It is understood that the Academy is engaged in the development of a horizontal display board facility (similar to that of the USN) which is to be used as an interim device prior to the development of a more sophisticated facility. It is assumed that the required features of this more sophisticated facility will be the following: (1) the need for simultaneous presentation of a large number of dynamically controllable aircraft and/or ground vehicles, (2) instructors' and pseudopilots' positions, (3) the capability for depiction of various weather conditions, (4) the capability for depiction of night-to-day levels of lighting, (5) the capability to accommodate, at the minimum, LC and GC positions, (6) the need for more than one tower simulator trainer in order to accommodate more than one training group at a time, and therefore, (7) the need to consider low relative costs, both initial and operating, and to consider the need for moderate spatial requirements.

The discussion of the previous section with regard to realism and training suggests that some as yet undefined amount of realism is desirable in a training simulator and that, although the radar-type display may not be desirable for extensive operations practice, some form of an interactive graphics display would be highly useful in the training laboratory. These considerations, along with those of the previous paragraph with regard to training needs, give rise to the analysis which follows.

TOWER CONTROL UNIQUE. Certain visual cues are used by tower controllers in their decision-making function which are unique and are not utilized by radar controllers. Tower control training should include practical experience with the use and application of these visual cues. These cues are not adequately represented by the horizontal display board, nor by a radar-type, plan view presentation of an airport area. Some of the advantages, in addition to realism, to be accrued from the development of a realistic visual-scene simulator-trainer are the capability for early selection procedures, and for producing tests having face validity.

CGI SIMULATION ADVANTAGES. Of the various methods of presenting visual-scene simulation, the computer-generated image technique far surpasses other methods: (1) in flexibility of instructional materials generation and modification, (2) in the ease and efficiency of storage of the image materials, (3) in the capability for the development of objective scoring materials, and (4) in the capability for computer-assisted instruction in order to relieve teachers of repetitive or routine instructional supervision.

TOWER REQUIREMENTS DEMONSTRATION. The tower simulation requirements have been discussed in detail with a number of CGI industry representatives. In their opinion, the technology can accommodate the requirements. However, it is impossible to propose a cost estimate until more specific requirements are defined. We, in turn, cannot specify more specific requirements until we view visual simulations of aircraft and airport scenes. Specifically, one of the most basic pieces of information needed for costing out a CGI system is the level of image detail necessary (which determines the amount of hardware circuitry in the image-generation component). Also, a decision must be made whether a random-write or a raster-scan system is required. As mentioned earlier, these differ considerably in cost. Therefore, what is needed is a demonstration by industry of a visual-scene simulation having a large number (15-25) of dynamically controllable aircraft and/or ground vehicles. As part of the demonstration there must be the capability to manipulate the number of faces (i.e., the level of complexity) with which the aircraft are "drawn." This elementary demonstration will yield the information needed in order to decide whether CGI as a simulation capability should be pursued further. The information gained would allow estimates to be made concerning: (1) the initial costs of a system, (2) the type of image system needed (i.e., raster-scan or random-write), and (3) the size and configuration of the simulator (i.e., projected or direct view, number of channels, size of screen, etc.)

PERCEPTUAL-VISUAL CUES STUDIES. Two types of evaluation studies should be carried out in order to improve the tower-training program. The first should be done whether or not a simulator device is developed, and the second is essential if a CGI system is to be developed. A study should be made, by survey and discussion with tower controllers, as to what visual information is actually utilized in tower control decision-making. Secondly, a determination must be made as to how these cues should be represented in a generated visual-scene. A direct one-to-one relationship with the real world in image generation is generally not done. Pure mathematical translations of runway widths, or aircraft details, for example, are not completely adequate for specifying

the numerical data base for the image-generator. Modifications of real sizes and proportions are frequently necessary to arrive at a realistic scene representation. Evaluative studies, using controllers as judges, would have to be carried out to arrive at the final scene representation. This would best be done at a facility such as NAFEC, since it would require only modification to the existing Digital Simulation Facility (DSF) in order to interface an image-generation prototype device for the purpose of carrying out the evaluation studies in the Computer/Controller Interface Laboratory. Controllers are available to act as evaluators for the general scene representation, and to aid in the development of aircraft image depiction. The purpose of the latter would be to achieve displayed images which provide aircraft recognition and differentiation, but which are "drawn" with as few faces as possible in order to maintain minimum data base storage and computation time.

MIDSIZE TOWER SIMULATOR. A tower training simulator using an out-the-window visual scene need not require a full-scale tower cab and large screen projection system. A midsize system can be developed based on the concept of the instructor's monitor console described in the Flight Simulations Summary Section (and pictured in appendix E). A tower simulator similarly configured would have these advantages; it would

1. Provide all the advantages of CGI technology (i.e., efficient data-base storage, ease of instruction material generation, objective scoring, etc.),

2. Provide a panoramic field of view (approximately 100° to 120°),

3. Accommodate LC and GC positions at the console,

4. Be cost efficient, and thus

5. Allow for the development of multiple training simulators,

6. Require relatively small spatial area for each trainer,

7. Use regular ceiling heights,

8. Be easily modifiable to present a three-dimensional, stereoscopic display when available, and

9. Be easily modified so as to eliminate the vertical bars between the monitors giving a clear, continuous scene.

The tradeoff in benefits to be gained from a simulator having these high-powered capabilities versus the relatively short development costs and development time involved make this system well worth further investigation.

STEREOSCOPIC DISPLAY. The advantages in terms of realistic depth perception that a stereoscopic display can provide has been discussed earlier. The notion of marrying the CGI technique with the stereoscopic display technology can be investigated easily. It would be a particularly suitable adjunct to the

laboratory demonstrations for the FAA by the CGI industry suggested earlier. A breadboard demonstration could be accomplished using a direct-view CRT presentation. This would require the development of PLZT ceramic glasses and a computer program (or the acquisition of the same from the Naval Undersea Center). The evaluation outcome of this demonstration would determine whether the development of a projected stereoscopic display (where PLZT ceramic glasses are not used) should be investigated. Either a direct-view CRT display or a projected image display, however, could be used for a simulator-trainer.

VOICE TECHNOLOGY. There have been rapid advancements in the computer speech understanding and generation systems over the past few years. One of the most beneficial features which voice technology has to offer ATC simulation training is its use as a replacement for the pseudopilots. The recent developments in speech understanding capability which make it possible to process complex syntax make it possible to consider the application of speech processing systems to ATC training. There are several potential uses for speech understanding systems (SUS) and for voice generation units (VGU):

1. To replace pseudopilots (e.g., controller messages would activate the target control program directly via SUS).

2. Pilot requests, responses, emergencies, etc., can be generated as needed by the dynamically running scenario via VGU (these are not preprogrammed "canned" messages).

3. SUS and VGU, as outlined above, could be used for basic control operations, coordination, etc.

4. Emergency pilot-calls could be programmed to occur during exercises at random intervals.

5. The student's performance can be evaluated by the computer program, and instructive comments generated during the exercise runs. The VGU would produce these comments during replay, thus reducing much of an instructor's routine "over-the-shoulder" observation and routine guidance.

6. Routine, basic exercises as described above could be performed on stand-alone, or time-shared, interactive graphics-display terminals, or they could be used with a visual-scene training simulator.

INTERACTIVE GRAPHIC DISPLAYS. The interactive computer terminal has had many uses in the education field. With the added feature of a fine-resolution graphics display, the device becomes particularly suited to the presentation of real-time air traffic problems.

Basic operations exercises (e.g., a series of departures, sequencing arrivals, etc.) could be displayed. Multiple-choice type questions could be superimposed, or interjected into the problem at certain points. Also, some data-input method (e.g., light pen, stylus and tablet) could be used to "control"

the aircraft to some extent. Display terminals currently on the market have logic, memory, and various other capabilities which make it possible to consider their use as stand-alone devices.

As discussed above under VOICE TECHNOLOGY, quite sophisticated training devices could be developed using the graphics display and SUS and VGU systems. Much routine ATC training could be accomplished at reasonable costs, with the capability to accommodate large numbers of students simultaneously, and with no great space requirements. While this device would make an excellent basic operations and phraseology trainer, it would not substitute for real simulation of airport tower-control operations.

CONCLUSIONS

It is concluded that:

1. The large number of visual-scene simulation facilities presently in use or under contract development for a wide variety of uses indicates that a tower-control application is entirely feasible.

2. Computer-generated image systems provide greater operational capabilities than other image-generating techniques.

3. A tower-simulator-trainer utilizing computer-generated image technology can be developed in various configurations (from a midsize, three- or four-channel display to a full-scale sophisticated system) and at various levels of cost.

4. A CGI simulation facility, midsize or full-scale, that provides a realistic tower environment could serve the FAA Academy in the functions of selection and training, the evaluation of developmentals, position qualification, and systems and equipment evaluations.

5. The current technology in large-screen projection systems (necessary for a full-scale tower simulation) can provide devices which would satisfy our anticipated requirements.

6. Job performance in airport tower-control LC and GC positions, relative to other ATC positions, is unique in involving the use of particular perceptual-visual cues in the decision-making process.

7. For the reason stated in (6) above, the use of a radar-type, plan view display for extensive, hands-on practice on tower-control training exercises may be detrimental because it sets the stage for potential negative transfer of learning from the training to the job performance.

8. A graphics display, or a radar-type display, and an interactive terminal could be used to provide practice and training in basic control functions. A dynamic situation could be shown on the display followed by a set of questions

which the student would answer on the terminal (or other input device). Immediate feedback could be given, and the student could proceed through a series of exercises at his own pace. The instructor would be free to provide specific help where needed rather than be involved with repetitive or routine instructions. These would be taken over by computerized instruction programs.

RECOMMENDATIONS

Based on the Training Requirements Assessment and the Simulation Technology Survey, it is recommended that:

1. HORIZONTAL DISPLAY-BOARD LABORATORY.

One or more horizontal display-board laboratories (similar in concept to that used by the USN, appendix C) should be installed at the FAA Academy as soon as possible in order to provide basic simulation training of airport tower-control operations.

2. INTERACTIVE COMPUTER-GRAPHICS DISPLAY LABORATORY.

A training laboratory consisting of interactive computer-graphics displays (similar in type to Picture System 2, appendix F) should be developed. This facility would provide an advanced capability for the presentation of academic materials and also a means to present basic, dynamic ATC operation exercises for all developmentals, radar as well as tower. A facility of this type would (a) relieve instructors of repetitive, routine teaching tasks, (b) provide objective methods for training and testing, (c) provide a capability for self-paced practice, and (d) provide an excellent capability for ATC phraseology training, in addition to the advantages already listed, if SUS system modifications (such as that in use by the USN for controller training, appendix F) were made to the displays.

The effort involved in the development of such a facility should include:

(a) The acquisition at NAFEC of a prototype device and basic software program for generating dynamic displays for the performance of studies, using NAFEC controllers as evaluators, in order to determine the perceptual and operational requirements of students and instructors as future users of the device.

(b) An investigation of the advantages of time-shared versus stand-alone console configurations.

3. COMPUTER SPEECH UNDERSTANDING SYSTEMS.

The progress of computer speech understanding and generation research work presently in progress should be monitored; in particular, that which uses controller vocabularies similar in complexity to that used in FAA operations (appendix F). This work is advancing rapidly in capability and should be

considered for application to the interactive graphics display consoles. Contracts should be let, as needed, to laboratories for producing demonstrations based on our requirements.

4. MIDSIZE CGI TOWER SIMULATOR.

The acquisition, in the future, of a CGI midsize, visual-scene tower simulator-trainer should be considered. A facility of this type (appendix E) would (a) shorten on-the-job training time, (b) establish a means for early selection and screening, and (c) provide a valid test instrument. These three needs have been emphasized in the IDA report (reference 5) as essential to the betterment of the FAA controller training program. The cost and special requirements of a midsize CGI simulator make it feasible to consider a multiple-laboratory configuration. The availablity at the Academy of such a simulation facility having a high level of realism would not only provide the advantages mentioned above with reference to the training program, but would provide also a capability for the evaluation of new operational systems and procedures by full-performance controllers.

The effort involved in the further investigation of the development of this facility would include:

(a) The establishment of a contract with one or more CGI producers to cover the costs of developing a computer program for demonstrating a capability to meet FAA requirements, in particular, the requirement to present simultaneously a large number of aircraft and/or ground vehicles.

(b) The acquisition at NAFEC of a CGI capability in order to perform perceptual-visual studies for establishing the functional requirements of the visual-scene generator (e.g., the number of faces required in the generation of an aircraft image, the minimum number of faces necessary to enable identification and differentiation of aircraft images, and the establishment of data-base requirements to provide adequate representation of terrain and environmental objects.)

(c) An enhancement of the CGI capability to present the visual-scene programs in stereoscopic format for evaluation at NAFEC. This would involve modifications to the image-generation programs and to the display hardware, both of which could be done in-house.

(d) The investigation of the application of computer speech understanding and voice generation systems to the visual-scene simulator for the purpose of eliminating most, or all, of the pseudopilots' responsibility.

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APPENDIX A

COMPUTER-GENERATED IMAGE SYSTEMS

Technological Concepts

Types of CGI Systems

COMPUTER-GENERATED IMAGE SYSTEMS

TECHNOLOGICAL CONCEPTS.

COMPUTER IMAGE GENERATION. The visual scene to be displayed is recorded as mathematical data and is taken from maps, charts, photographs, or created as necessary. The surface terrain and surface objects, such as airport areas and environmental lighting, are modeled in numeric form and stored in the memory of the image generator computer. The terrain features and environmental objects are represented by arrangements of edges (vector lines), vertices (points in a coordinate system), and faces (surfaces created by bounding edges) as shown in figure A-1. Objects are made up of various numbers of faces. The edges and vertices are defined numerically relative to a referent coordinate system (figure A-2A) established for the particular model. A data base, or description, of the objects is stored in the bulk memory of a digital computer. A perspective view on a view plane as seen from the observer's eye-point (figure A-2B) is calculated. Continuous perspective views of an area are computed and generated for real-time simulation. The complexity of CGI systems is described variously by the number of edges, faces, or vertices that can be accommodated in any individual scene. References 19, 20, and 21 provide detailed descriptions of the CGI concepts.

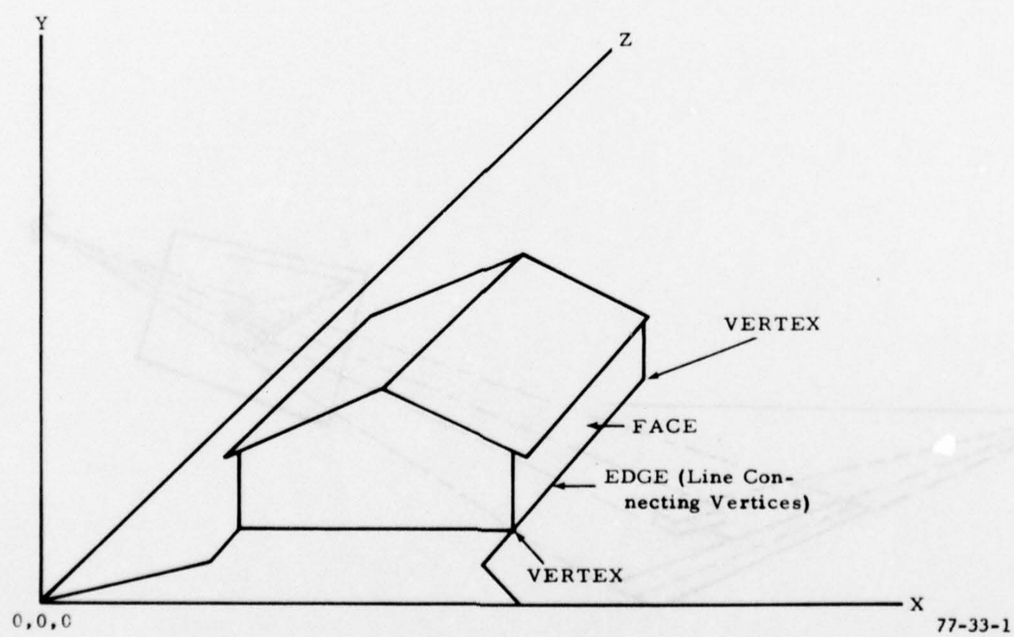
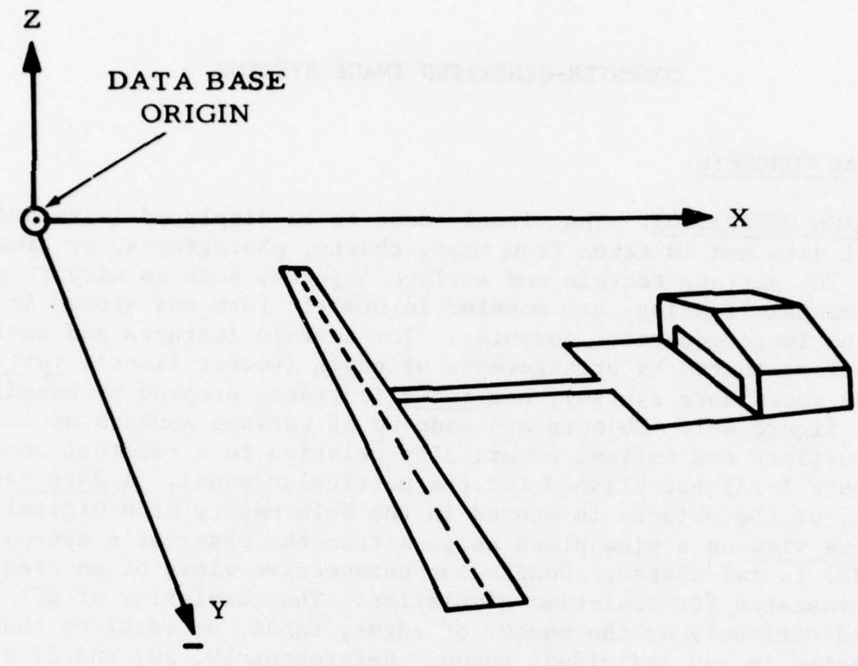
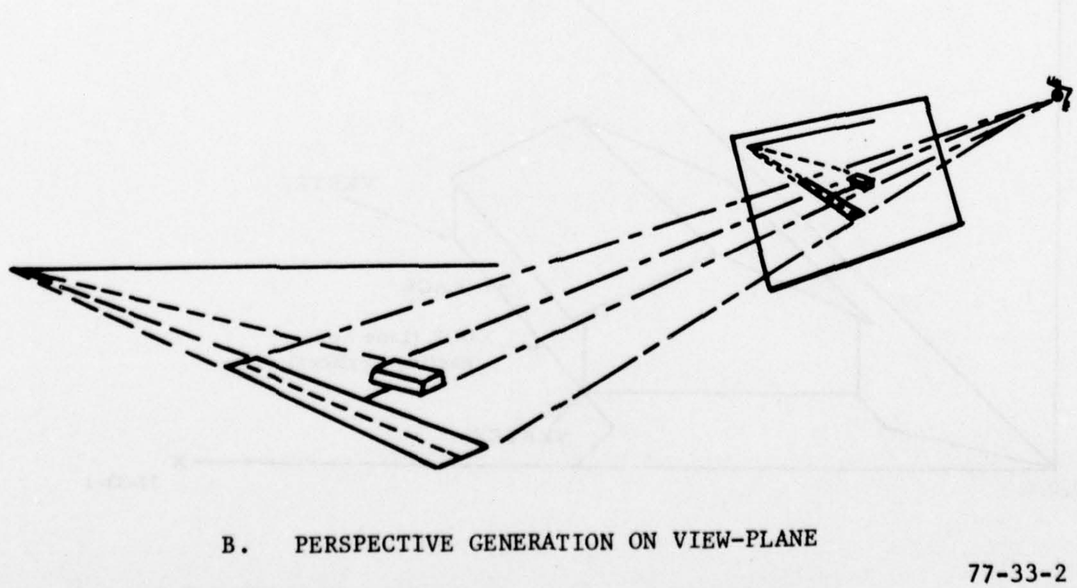


FIGURE A-1. ELEMENTS OF NUMERICAL MODEL OF COMPUTER-GENERATED IMAGE



A. REFERENT COORDINATE SYSTEM



B. PERSPECTIVE GENERATION ON VIEW-PLANE

77-33-2

FIGURE A-2. COMPUTER-GENERATED PERSPECTIVE

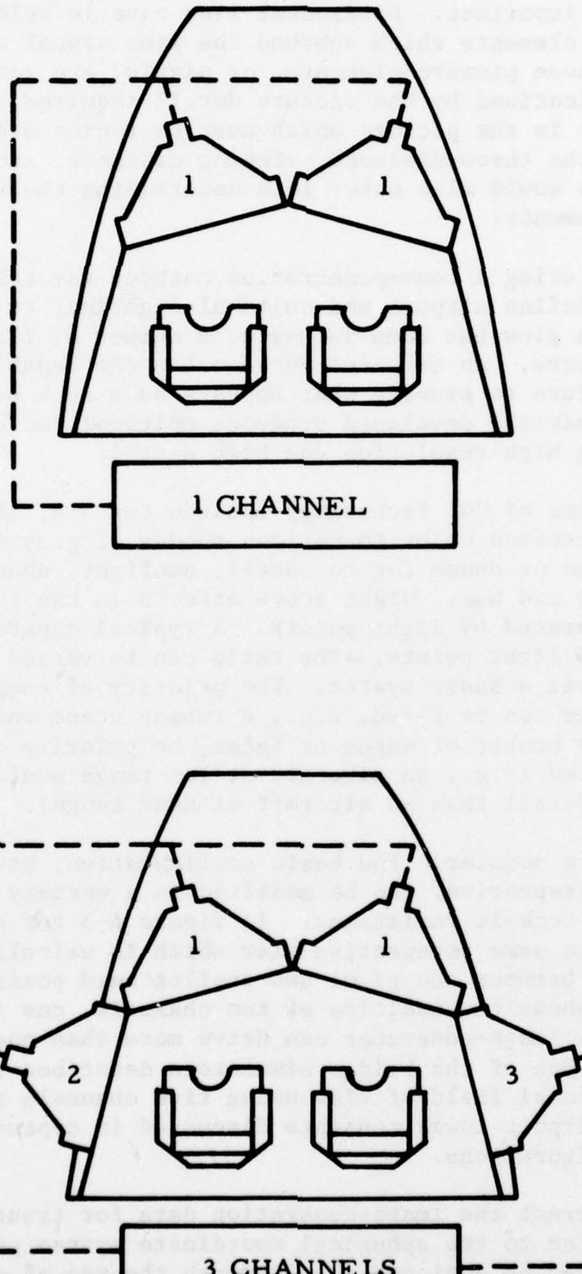
In raster-scan systems, resolution corresponds to the raster configuration: lowest resolution is obtained with the standard 525-line raster, intermediate with the European 625- or 770-line raster, and higher resolution is available where scene detail is important. Horizontal line rate is selected to provide horizontal resolution elements which subtend the same visual angle as the vertical elements. Those picture elements, or pixels, are generally determined for functional specifications by the picture detail required, such as the size of the smallest object in the picture which must be represented. The size of the projected image, the throw-distance, viewing distance, and to some extent contrast and luminance would also enter into determining the specifications for resolution requirements.

A calligraphic system using a beam-penetration cathode ray tube (CRT) display with light points to define airport and cultural lighting, to outline buildings, and to provide horizon glow has been in use at a number of flight training centers for several years. An enhanced version has the capability of displaying solid objects and texture to provide what appears as a dusk scene. Another calligraphic system recently developed produces multicolored day, night, and twilight scenes having high resolution and high detail.

Some visual capabilities of CGI technology include texture, aerial haze (natural effect of decreased color to various shades of gray at the horizon), visibility ranges (zero or dense fog to ideal), sunlight, shadows, clouds, curved surface shading and hue. Night scene effects in the raster-scan configuration are generated by light points. A typical capability is a mix of 10,000 edges and 2,000 light points. The ratio can be varied or doubled with additional hardware over a basic system. The priority of complexity assigned to objects in the scene can be fixed, e.g., a runway scene which would always be drawn with the same number of edges or faces, or priority can be relative and dynamically computed (e.g., an aircraft at far range would be drawn with fewer edges and less detail than an aircraft at near range).

The various systems are modular. The basic configuration, having a single channel, or viewing perspective, can be modified in a variety of ways. Figures A-3 and A-4 show some cockpit variations. In figure A-3 top drawing, the pilot and copilot receive the same perspective view which is calculated generally from a point half-way between the pilot and copilot head positions. Figure A-3, bottom drawing, shows the addition of two channels, one for each side-window view. A single image-generator can drive more than one cockpit as shown in figure A-4. One of the bridge simulators described in appendix D achieves a 240° horizontal field of view using five channels and large-screen projection. The GE airport tower concepts discussed in appendix C used four- and five-channel configurations.

Projection systems correct the image-generation data for transformation from a flat coordinate system to the spherical coordinate system perceived by the eye. Transformation can be achieved also through the use of collimating optics which form a virtual image of the CRT at infinity. A typical cockpit installation is shown in figure A-5. A virtual image of the CRT is formed by the beam splitter at the focal surface of the spherical mirror which then images the surface at infinity as perceived by the viewer located near the center of the curvature of the spherical mirror.



77-33-3

FIGURE A-3. SINGLE-CHANNEL AND MULTIPLE-CHANNEL CONFIGURATION

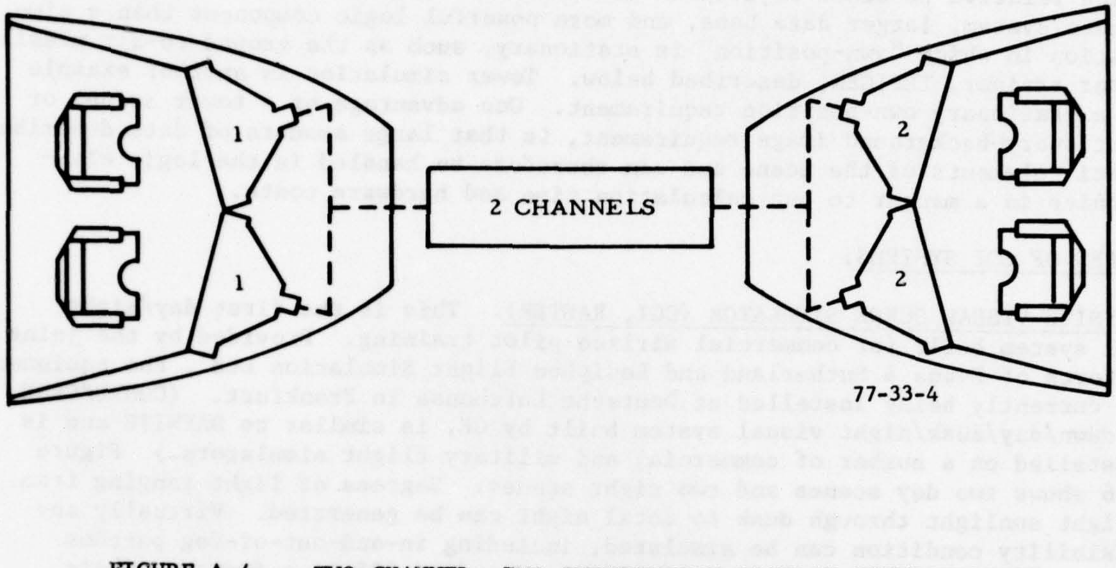


FIGURE A-4. TWO-CHANNEL, TWO-INDEPENDENT-DISPLAY CONFIGURATION

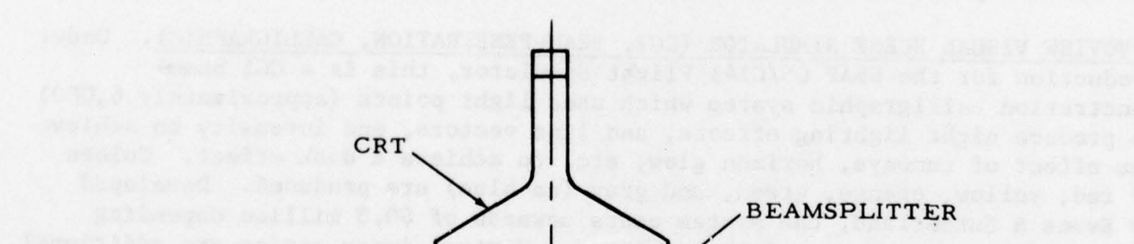


FIGURE A-5. INFINITY IMAGE OPTICS CONFIGURATION

Flight or marine simulation utilizes a viewing perspective which moves in space relative to other objects in the scene and requires a more complex coordinate system, larger data base, and more powerful logic component than a simulation in which "own-position" is stationary, such as the ground-to-air missile aimer trainer, TEPIGEN, described below. Tower simulation is another example of a stationary own-position requirement. One advantage of a tower scene, or stationary-background image requirement, is that large amounts of data describe static elements of the scene and can therefore be handled in the logic electronics in a manner to cut calculation time and hardware costs.

TYPES OF CGI SYSTEMS.

DAYNITE VISUAL SCENE SIMULATOR (CGI, RASTER). This is the first day/night CGI system built for commercial airline pilot training. Provided by the joint efforts of Evans & Sutherland and Rediphon Flight Simulation Ltd., the equipment is currently being installed at Deutsche Lufthansa in Frankfurt. (COMPUSCENE, a dawn/day/dusk/night visual system built by GE, is similar to DAYNITE and is installed on a number of commercial and military flight simulators.) Figure A-6 shows two day scenes and two night scenes. Degrees of light ranging from bright sunlight through dusk to total night can be generated. Virtually any visibility condition can be simulated, including in-and-out-of-fog patches and clouds. The system is raster-scan in standard 625-line format. Costs depend on specific needs of the customer, but would range from $1.5 million upwards. This simulation was viewed on video-tape on a TV monitor. Despite the resulting degradation, the enhanced visual detail over the work produced for the early CAORF system was apparent.

NOVOVIEW VISUAL SCENE SIMULATOR (CGI, BEAM-PENETRATION, CALLIGRAPHIC). Under production for the USAF C5/C141 Flight Simulator, this is a CGI beam-penetration calligraphic system which uses light points (approximately 6,000) to produce night lighting effects, and line vectors, and intensity to achieve the effect of runways, horizon glow, etc. to achieve a dusk effect. Colors of red, yellow, orange, green, and gray (no blue) are produced. Developed by Evans & Sutherland, the system costs upwards of $0.3 million depending on specific requirements of the customer. Virtual image optics are additional.

VITAL IV VISUAL SCENE SIMULATOR (CGI, BEAM-PENETRATION, CALLIGRAPHIC). This system is a recent development of McDonnell Douglas. It uses a calligraphic technique and a beam-penetration display to produce scenes of high resolution (unique to calligraphic systems) and high detail (previously achieved only with lower resolution raster-scan systems) to achieve day, twilight, and night effects. The scenes portrayed are made up from hundreds of faces and thousands of light points. There are cost advantages of a calligraphic system over raster-scan technology; however, one problem has been the capability to produce a number of simultaneous aircraft images using a random write, or calligraphic, deflection system. The high-detail capability claimed here may eliminate this as a problem.

TEPIGEN (CGI, RASTER). This CGI system was originally built by Marconi Radar Systems, Leicester, England, in collaboration with the Admiralty Surface Weapons Establishment for the Ministry of Defense Procurement for shore training of

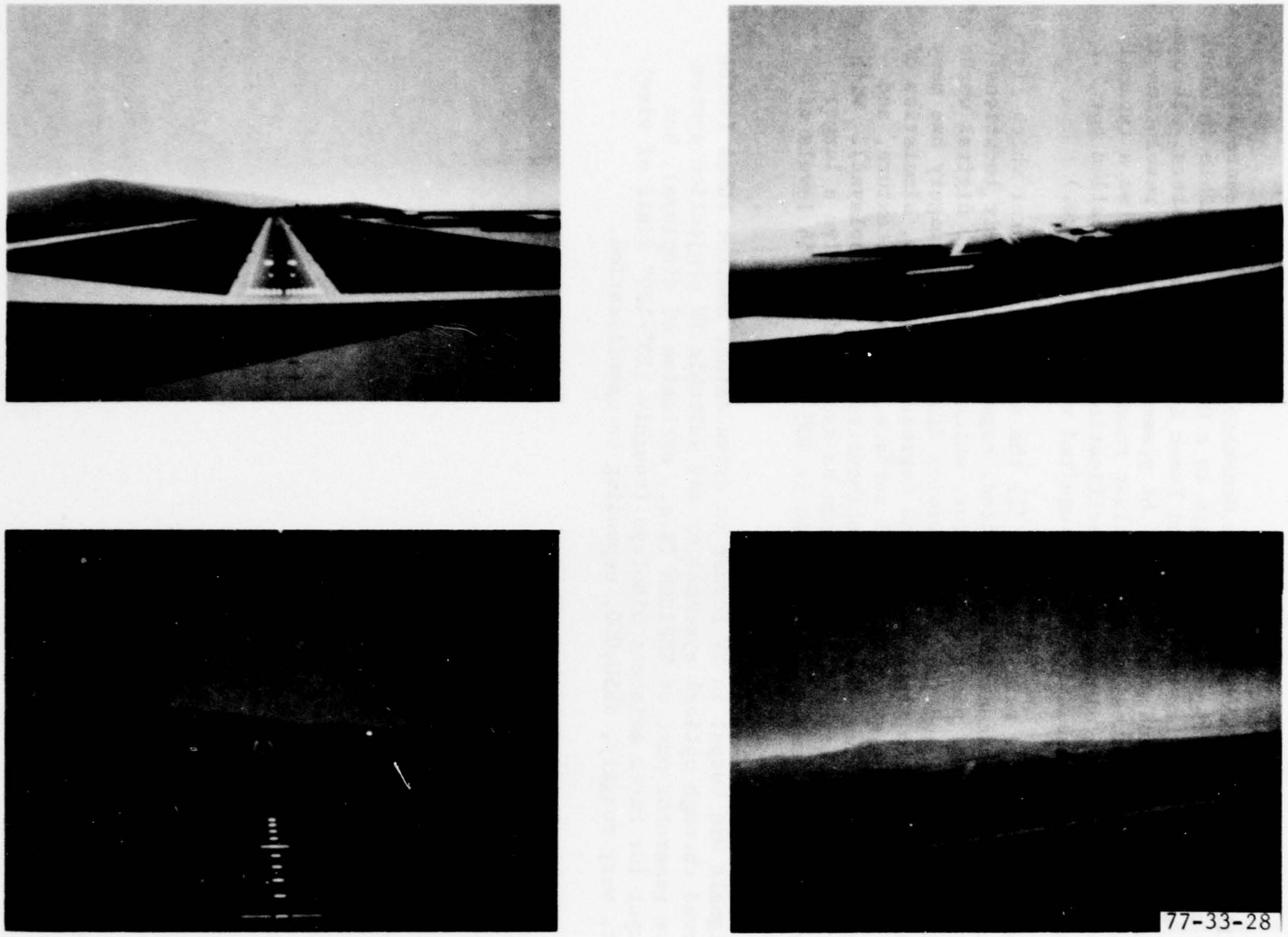


FIGURE A-6. SCENES FROM LUFTHANZA FLIGHT SIMULATOR USING CGI DAYNITE SYSTEM

naval missile aimers. Television Picture Generator (TEPIGEN) presents a picture on a TV display (figure A-7). This is a CGI system available in black and white, or color, similar to the GE and Evans & Sutherland systems. It can provide high resolution and good acuity. At present, a 770-line resolution is used providing 3 arc minutes for the smallest resolvable element at a typical field-of-view and viewing distance. (Specifications for COARF called for 7.2 arc minutes line-pair resolution at the required viewing distance.)

TEPIGEN consists of three main elements: (1) the scenario computer which lists all the elements of the scene to be depicted, together with their locations and orientations, (2) the picture generator, which converts the digital words of the list to TV signals, and (3) the television display. The imagery has many sophistications--variable light levels and degrees of contrast, simulation of raindrops falling on the external optical surface, moving sea texture, and three-dimensional modeling (even when a silhouette only is displayed). With projected systems, a mosiac of displays can be assembled to give a larger field of view. Total number of faces seen is 400-2,000 with 64 levels of face priority.

TEPIGEN signals are output in TV format to drive either monitor tubes (which may be viewed through optical systems) or any suitable TV projection system. The picture generator part of TEPIGEN (i.e., exclusive of displays), but giving output for three adjacent displays (roughly 110°-120° field of view) would cost, very roughly, $850,000, depending on specification.

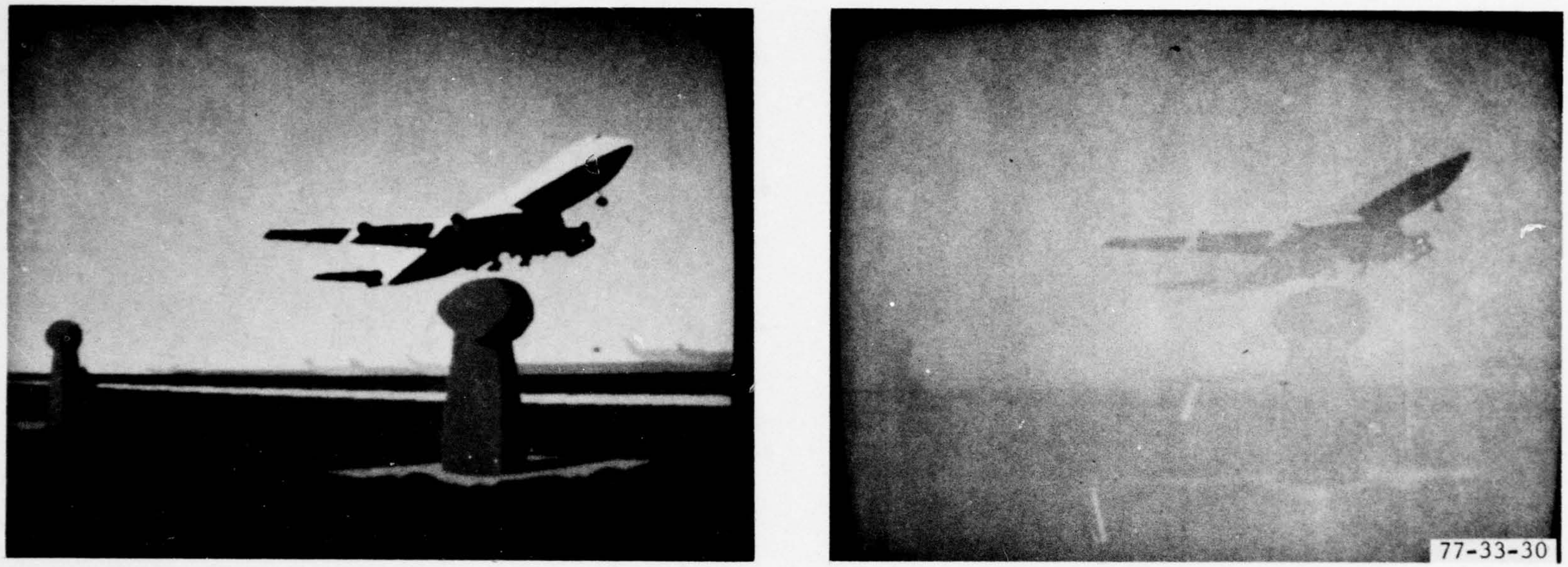


FIGURE A-7. TEPIGEN COMPUTER-GENERATED IMAGE OF A 747 IN GOOD AND BAD VISIBILITY

APPENDIX B

PROJECTION DEVICES

Stereoscopic Image Generator

Light-Valve Projector

PROJECTION DEVICES

STEREOSCOPIC IMAGE GENERATOR.

An electro-optic shutter viewing device utilizing lanthanum zirconate titanate (PLZT) ceramics to produce stereoscopic visual effects when used with real-time TV or computer-driven CRT displays has been developed at the Naval Undersea Center by Dr. John Roese. The principles of the device and several applications are described in references 22, 23, and 24. The basic principle is that of alternately blocking and unblocking for each eye the perspective view of the object observed. For example, when viewing the typical 2:1 interlace CRT display, the glasses having PLZT ceramic lenses function as electronic shutters with each lens 180° out of phase with the 50-percent duty cycle of the TV format. The perspective view for one eye is seen during the first field scan, while the other eye is blocked. This process is then reversed for the second field scan, providing the perspective view for the other eye. The schematics of figures B-1 and B-2 show the photographic and display systems.

The effect of viewing the TV screen without the glasses is that of a somewhat "fuzzy" picture in need of a bit of fine tuning. Upon putting on the glasses the scene immediately takes on realistic depth. The subjective feeling expressed by a number of viewers is one of being able to reach into the picture. One demonstration was the operation of an automated arm in action which gave the distinct feeling that the arm was reaching out in real space and that one could reach in and around behind the arm. Another demonstration was a view of sailboats in the bay area. The effect of depth and distance across the water was very real, and effect of parallax was powerful. The effect was equally powerful when presented on an Advent screen, but suffered from the normal disadvantages of the Advent viewing system, i.e., distortion and reduced brightness of the viewed scene as the observer moved from the preferred viewing point. The automatic arm and the sailboat scenes were originally made with two TV cameras positioned approximately 40 centimeters (cm) apart. Another demonstration used digitized data representing the view of a portrait as perceived from each eye. Again, the depth cues were subjectively real.

The latter demonstration suggests the very powerful potential of marrying the stereoscopic projection with the CGI software package. Two perspective views (equivalent to two channels) of any scene in the data base can be generated and updated as required for real-time simulation. An airport scene could take on all the realism of depth perspective, and parallax cues as experienced in real life.

The disadvantage of the viewers having to wear special ceramic lens glasses, which at the present time are quite expensive, about $4,000 per pair (although it is expected to be half that amount shortly), can be eliminated by the use of an alternative system configuration which utilizes a projection technique. Left- and right-eye-perspective image pairs are projected alternately on successive field scans of a video frame. "An electronically controlled light-rotating device and a linear polarizer are used in conjunction with a high-

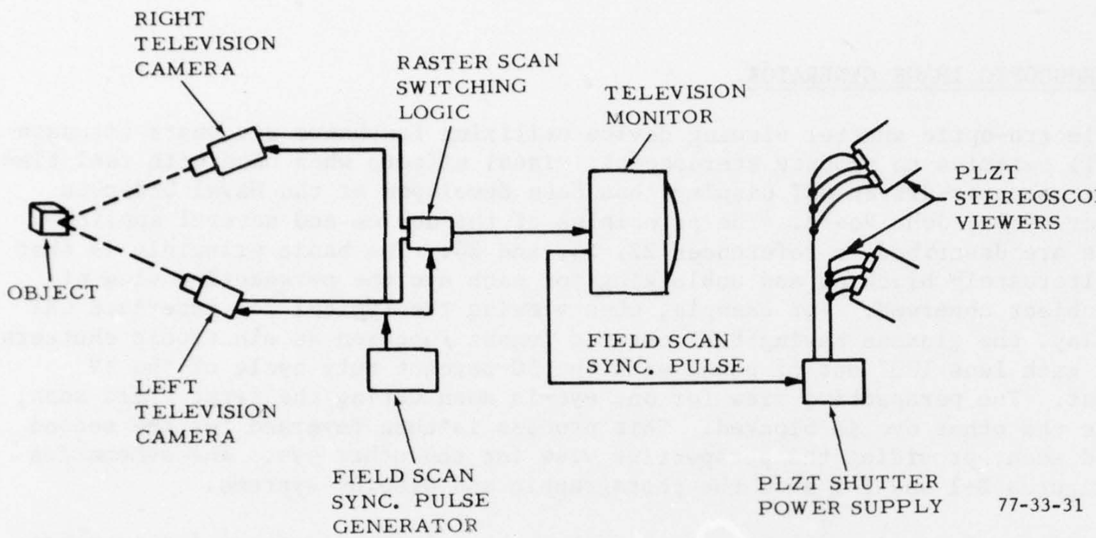


FIGURE B-1. TWO-CAMERA PLZT STEREOSCOPIC TV SYSTEM

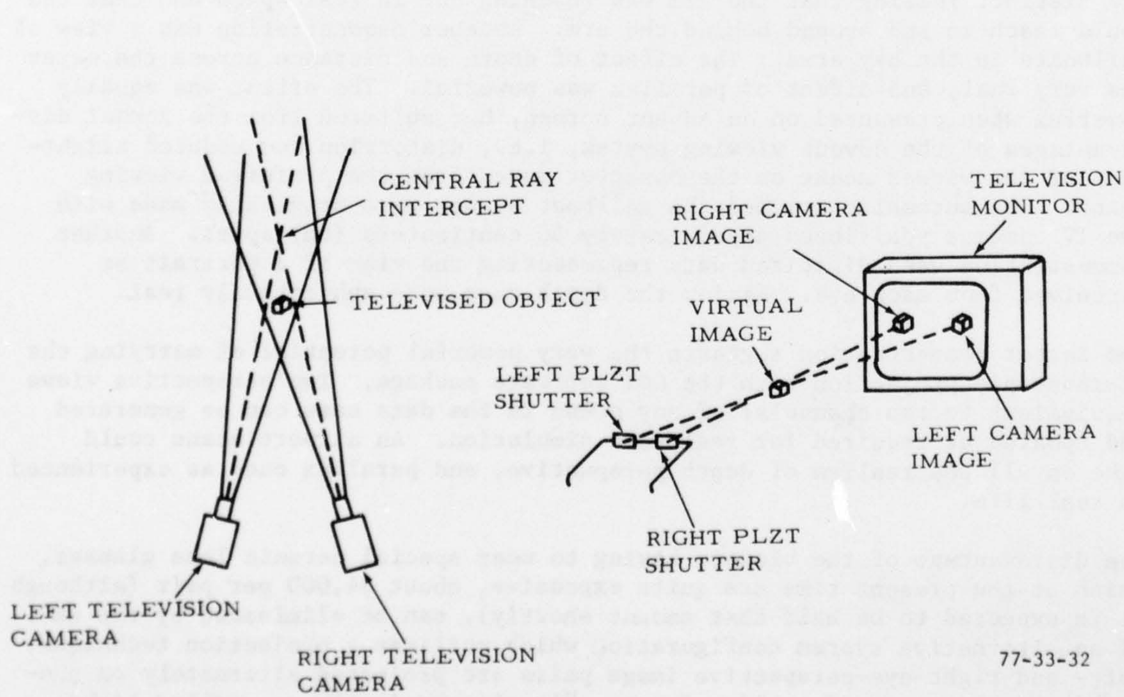


FIGURE B-2. BASIC STEREOSCOPIC TV DISPLAY GEOMETRY

quality video projection system to project orthogonally polarized steroscopic image pairs. The three-dimensional video images present a well defined depth of field which is readily viewable by observers wearing simple polarized viewing glasses," as summarized in the abstract of reference 23. The light-valve projection system would be preferable to the Advent system because of its increased brightness capability and less restrictive preferred viewing point requirements. Flexibility in projection system configurations and the capability for juxtaposition of projected scenes to achieve a panoramic effect are available with the light-valve system, but would be difficult to achieve with the Advent.

LIGHT-VALVE PROJECTION SYSTEM.

The General Electric Light-Valve is a large-screen television projection system. It could be adapted for use in other systems described herein. The principle of operation is similar to the Eidophor used in the CAORF system. The electron gun, oil bath, mirrors, drives, lens system, etc., are housed within a single tube in a high vacuum. This alleviates many of the problems associated with the Eidophor system (reference 25). The unit is extremely reliable, providing all but 1 hour per day operation in a two-shift, three-light-valve operation for the Navy in flight simulation. This includes all corrective maintenance, preventive maintenance, alignments, data changes, etc. Each system is relatively cheap and operating costs average $10 per hour. This unit may be driven by any available TV video-generating system, including computer-derived, television camera, scan converter, or flying spot scanner. The displayed images are quite bright, providing approximately 22 footlamberts (fL) at a throw distance of 20 feet. This is brighter than the images produced for CAORF (appendix D) by the Eidophors and brighter than that required by the functional specifications of the USAF Tower Simulator (appendix C).

The light valve may be used as a component of the McDonnell Douglas Multiple Flight Simulation (appendix E), the CAORF, and possibly in the USAF Tower Simulator systems.

The advantages of the GE light valve are:

1. Reasonable cost,
2. Flexibility,
3. Off-the-shelf availability,
4. Standard parts,
5. Reliability, and
6. Ease of maintenance.

The disadvantages are:

1. Initial cost is relatively high, and
2. Single source for procurements.

APPENDIX C

CONTROL TOWER SIMULATORS

USAF Control Tower Simulator

USN Control Tower Trainer

DML Tower Demonstration Model

GE Tower Simulation Concepts

Canadian Airport Trainer

NAFEC Tower Simulation Model

USAF CONTROL TOWER SIMULATOR (TOWER CAB, PANORAMIC SCREEN, PHOTOGRAPHED IMAGES).

The USAF has contracted for a control tower simulator for installation at Keesler Air Force Base (AFB), Mississippi, to be used as a training facility. The contractor, AAI Corporation, permitted FAA personnel to see the simulator (not in operation, however) at its Cockeysville, Maryland, facilities. Installation at Keesler is currently underway. The simulator, designated by the USAF as AN/GSN-T3, is designed to provide a realistic simulation of a modern Air Force control tower in real-time by generating up to 12 simultaneously viewed images, or targets, representing ground vehicles and aircraft. (Figure C-1 presents an artist's concept drawing of the facility, and figure C-2 shows the floor plan.) The system costs were approximately $4.2 million, exclusive of buildings.

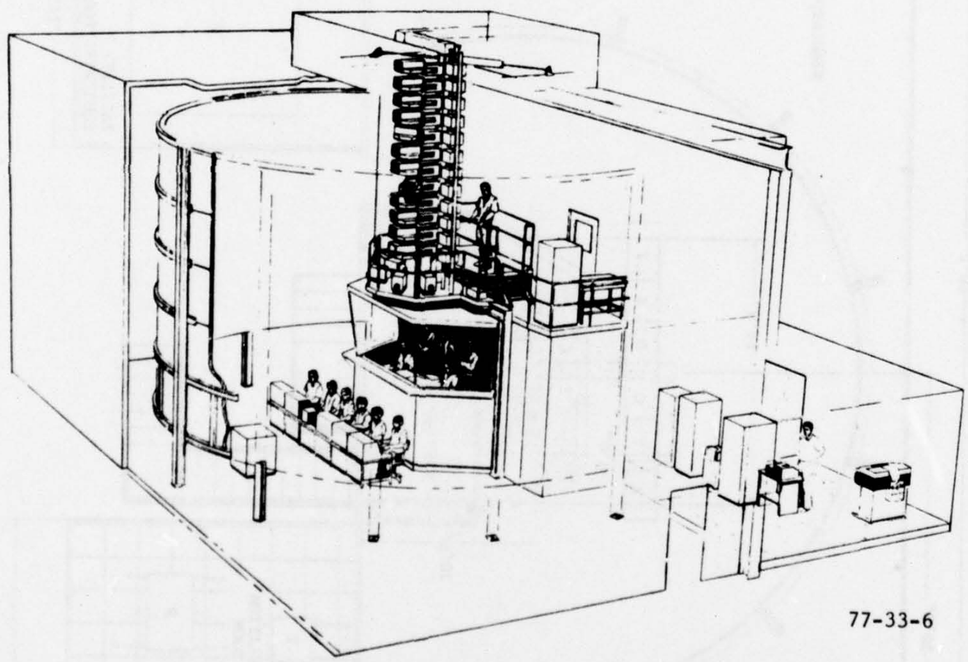
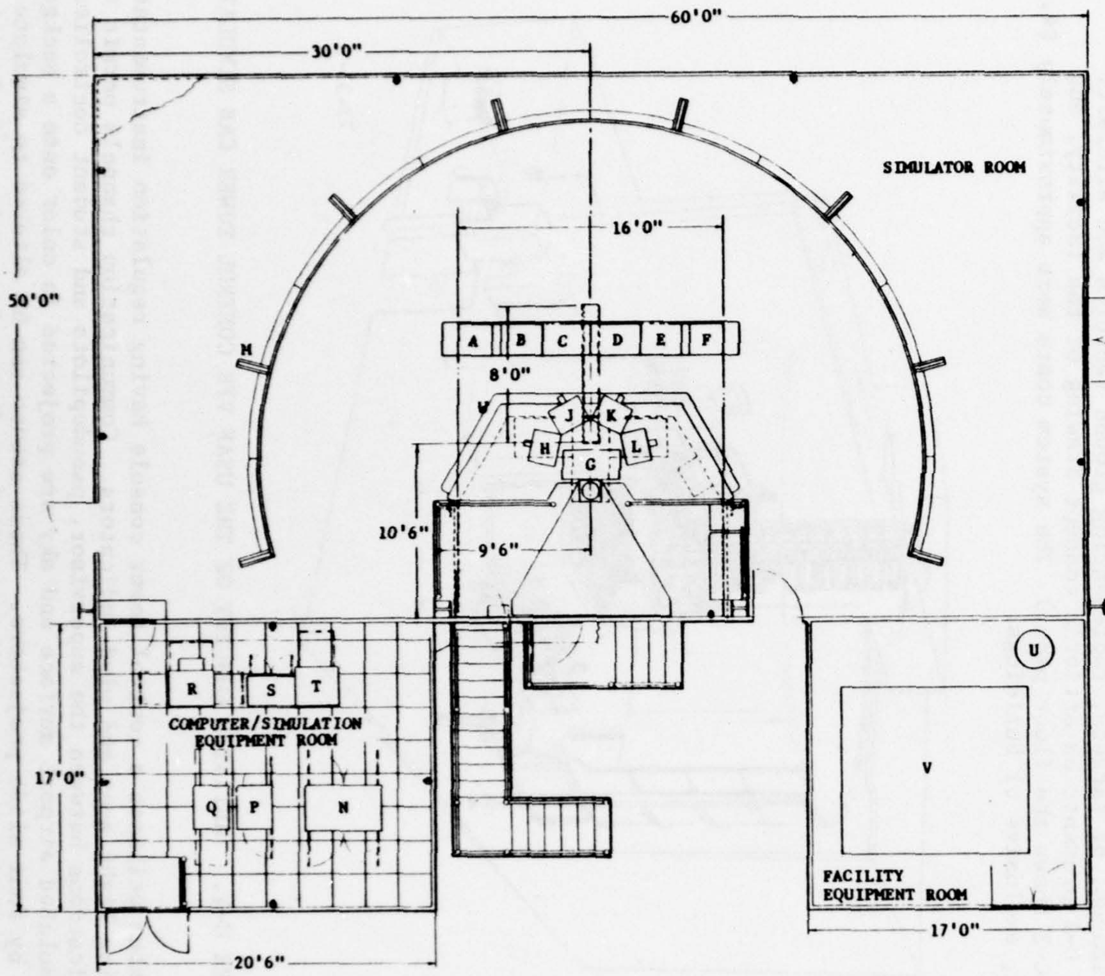


FIGURE C-1. ARTIST'S CONCEPT OF THE USAF VFR CONTROL TOWER CAB SIMULATOR

The system utilizes a control tower console having regulation instrumentation including light guns and wind indicators. Communication channels permit voice communications between the supervisor, pseudopilots and student controllers. The simulated airport surface and sky are projected in color onto a background screen by four slide projectors. These scenes can be altered to simulate day or night and various weather conditions (e.g., fog, rain, and clouds).



CABINET IDENTIFICATION KEY

A. Pseudo-Pilot Console
B. Pseudo-Pilot Console
C. Supervisor's Console
D. Airfield Facilities Console
E. Pseudo-Pilot Console
F. Pseudo-Pilot Console
G. Target Projector Tower with 12 Projectors
H. Background Projector
J. Background Projector
K. Background Projector
L. Background Projector
M. Projection Screen and Support
N. Interface/Communications Cabinet
P. Computer
Q. Disc Unit
R. Line Printer
S. Card Reader
T. Teletypewriter
U. 400 Hz Generator
V. Air Conditioner
W. Simulated Cab with AN/GSA-135 Control Tower Console

77-33-7

FIGURE C-2. FLOOR PLAN OF USAF VFR TOWER CAB SIMULATOR

Aircraft and ground vehicle images are projected in color from 35-millimeter (mm) film strips. Seventeen types of aircraft and four types of ground vehicles can be presented. Computations for target trajectories and target projector control are performed by a general purpose mini-computer system which controls changes in azimuth, elevation, and range. Sound simulation for the various types of vehicles (such as afterburner and crash crew sirens) is also provided.

Four pseudopilot consoles and one training supervisor console are located in front of, and below, the tower cab out of the trainee's line of sight. The 12 target projectors are mounted on a post located above the tower cab. The screen provides a 210° horizontal and 46° vertical field of view. The area housing the simulator is 60 feet by 33 feet and requires a 32-foot ceiling to accommodate the projector support post.

The target projectors are specially built dual-lens systems, each equipped with two film reels of 8,000 frames each. The attitudes and various sizes of all ground vehicles and aircraft are supplied on each reel. Size changes are also achieved by lens zooming. Figures C-3 and C-4 show schematic drawings of the projectors. Vertical movements of the images are accomplished by moveable mirrors in the projector's optic system, and azimuth changes are accomplished by horizontal rotation of the projector. The dual-lens provides the capability to fade-in successive frames to achieve size changes beyond that produced by the zoom alone.

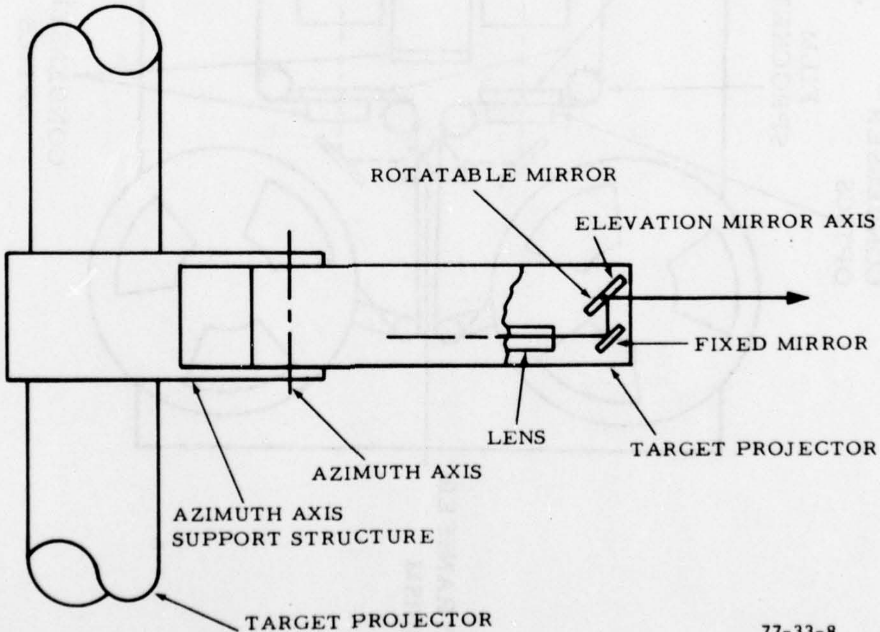


FIGURE C-3. USAF TOWER CAB SIMULATOR PROJECTOR ASSEMBLY SCHEMATIC (ELEVATION PROFILE)

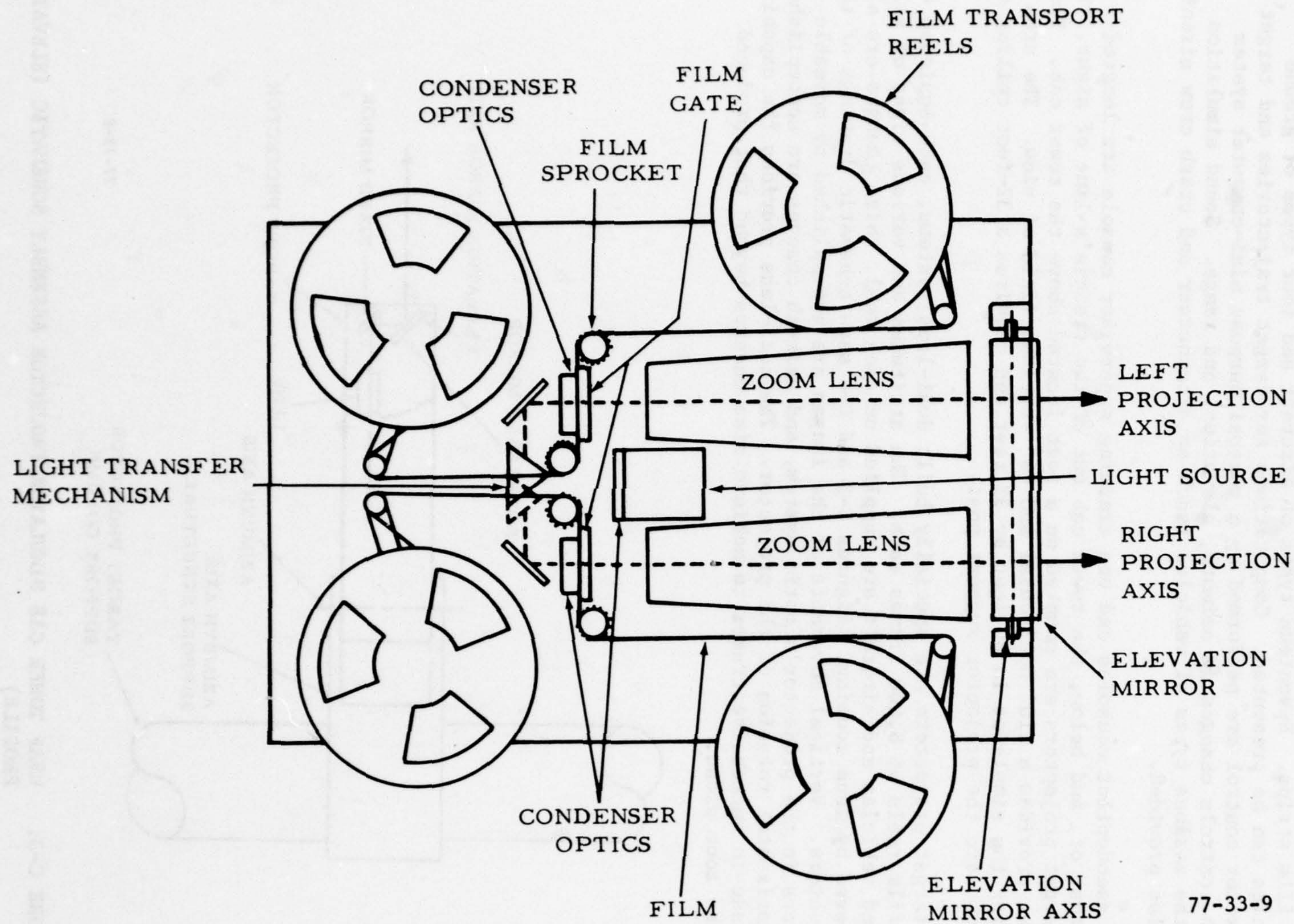


FIGURE C-4. USAF TOWER CAB SIMULATOR TARGET PROJECTOR SCHEMATIC DIAGRAM

A repertoire of about 70 ATC and "event" instructions is available. All can be entered at the instructor's console, about half at the pseudopilots' keyboard, and about two-thirds can be implemented via the preprogrammed traffic scenario. (The pilot keyboard and display data are shown in figures C-5 and C-6.) Some of the instructions that can be entered by the instructor or via the scenario (but not by the pilot) are initial heading, altitude, and speed of aircraft, ground vehicle speeds, sirens, failure to lower gear at normal approach point, afterburner sound, delayed response to target commands, advance and delay of scenario events, wind, weather conditions, and visibility. Among the repertoire of pilot instructions are "go to X,Y,Z" (for taxiing aircraft point to point), rectangular approach, right base leg, left base leg, 360° overhead approach, straight-in approach, simulated flameout, full stop, touch and go, stop and go, low approach, takeoff, intersection takeoff, takeoff abort, hover, rock wings, hold (on ground), wheels down, 270° turn to base leg (instead of the usual 90° turn), 360° turn on downwind leg, runway change, landing light ON, extend downwind leg by ___ seconds, shorten approach, go around, turn right ___ degrees, turn left ___ degrees.

Although originally scheduled for final checkout in December 1976, the simulator's checkout and acceptance testing were delayed due to problems in obtaining film that meet the image registration criteria. One of the problems has been the unacceptable visual effect of image "jumping," or an animation effect, when successive film frames are projected, for example, as the aircraft image changes in attitude or size. This evaluation of the USAF simulator is based on a visual inspection of part of the final system and on what was learned through discussion with AAI personnel and from their literature. Two background projectors and a single target projector were used in the demonstration. The system did not provide target motion. Luminance was relatively dim, but probably adequate. Where superimposition of projected images occurred, both images were visible to some extent.

The USAF system is the only computerized control-tower simulator that provides an "out-the-window" scene of an airport and airport traffic. This unique system seems to provide everything that a control-tower simulator should provide. The visual effects, to the extent they were available for observation, appeared adequate. Detail in the photographed scene was superior to that produced by CGI techniques. Smoothness of aircraft image movement could not be determined. The simulator could be an effective trainer for tower controllers.

Like the Computer Aided Operation Research Facility (CAORF), the USAF simulator is large in size, great in price, and relatively small in training capacity. There is no reason to suspect that, if the system is demonstrated to be operationally acceptable, maintenance should be extremely difficult. However, cost of maintenance upkeep may be high. The heavy-duty gimbals of the projectors have to be specially precision machined, and, if parts replacement is required, the cost may be high. Servicing the projectors is awkward, since they are placed one above the other vertically and they are very heavy, causing difficulties in removing and replacing. These problems can be overcome by the construction of platforms for access and some manner of jigs and hoists for removing and replacing. Removing and replacing is desirable, because the system cannot be readily operated while being serviced inplace. The rest of

TIME 5:22:38 PROBLEM STATUS: FREEZE

TARGET	A F1-L	B	C
IDENT	KING 54	ZOOM1	L231
TYPE	T-38 (23)	CRASH (20)	DC10 (18)
ACTIVE FUNCTION	360 OVERHEAD	GOTO 83, 90, 96	GOTO 21, 19, 18
RUNWAY	21R		
VARIATION	MIDFIELD BRK	HOLD	
PSN/REP	INITIAL/BREAK	SLOT 83/SLOT 90	SLOT 19/
PENDING FUNCTION	FULL STOP	GOTO 97, 98, 156	TAKE-OFF
PENDING FUNCTION	GOTO 79, 77, 67		
RANGE/BEARING	2.1 /NW	1.5 /NE	1.2 /N
ALTITUDE	6000	1641	1641
HEADING	270	110	95
SPEED	240	35	25
GEAR/LIGHTS	UP-OFF	DOWN-OFF	DOWN-OFF

A -
B -
C - CONTACT TOWER FOR TAKEOFF AT SLOT 18
COMMAND ERROR

FIGURE C-5. PSEUDOPILOT CRT DISPLAY DATA

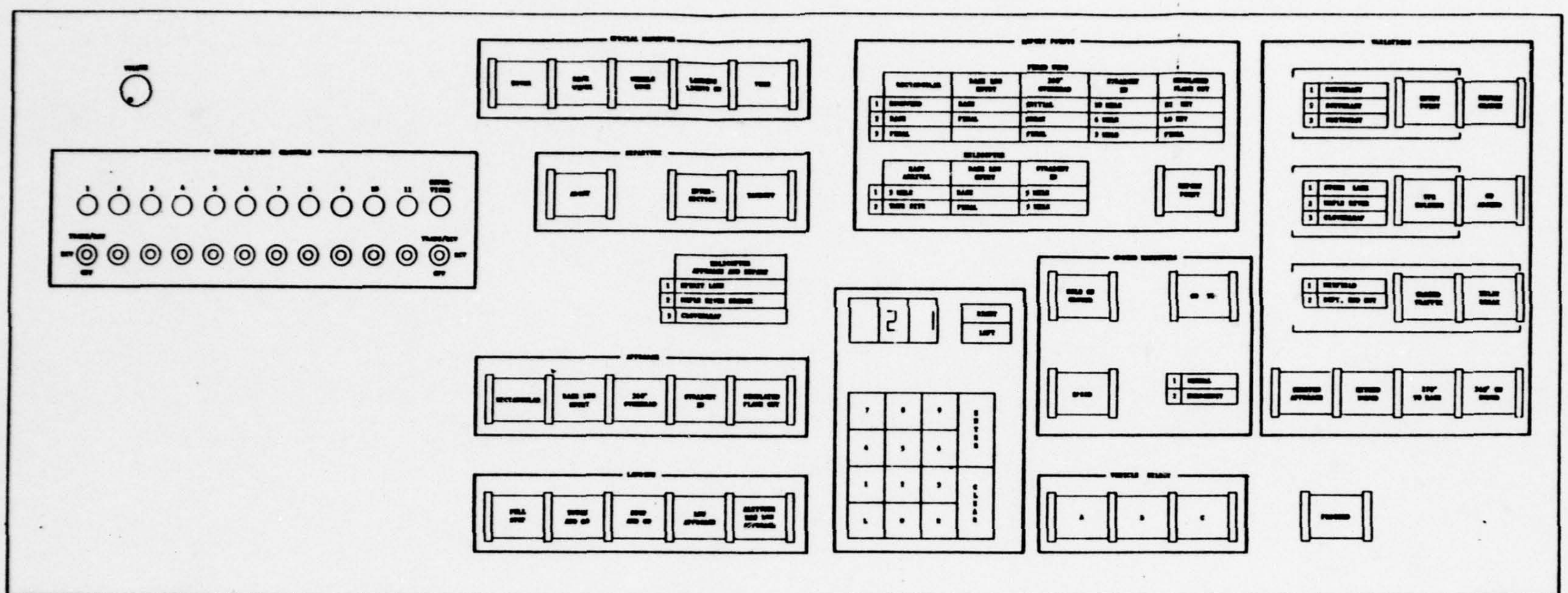


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FIGURE C-6. USAF TOWER CAB SIMULATOR PSEUDOPILOT FUNCTIONAL PANEL AND COMMUNICATIONS PANEL

the system is of standard electronics and parts which should create no special problems. The life of the film strips will depend on the number of hours of continuous running time, the amount of exposure to heat, and film quality. Color-matching may present a problem if new strips are intermixed with older ones.

USN CONTROL TOWER TRAINER (TOWER CAB, HORIZONTAL DISPLAY BOARD, MODEL AIRCRAFT).

Installed at the Naval Air Technical Training Center, ATC school, in Millington, Tennessee, the United States Navy (USN) tower trainer uses plastic scale models of aircraft suspended from sticks with a line and pulley mechanism to change aircraft configurations, and a large table area to represent an airport surface. The models are walked around the runway by pseudopilots in response to commands received via headset from student controllers. A three-window tower cab overlooking the display area is used to simulate the tower environment. Figure C-7 shows students in the tower cab and figure C-8 gives a view of the simulation pilots operating the aircraft on the display board. This system provides three-dimensional information via the relative altitudes and ranges of the aircraft models and also provides a realistic communication system.

DML TOWER DEMONSTRATION MODEL (TOWER CAB, CGI DISPLAY ON CAB WINDOWS).

Digital Methods Limited (DML), Ottawa, Canada, produced this demonstration model for the Ministry of Transport of Canada at the Uplands Laboratory facility. The basic concept was to provide a visual scene of aircraft and airport features on screens positioned in the windows of a tower cab. A computer graphics display driven by an SEL 810B provided vector representation of a DC9 and runway (figure C-9). A comprehensive software capability was developed for simulation of flight characteristics, for generation of flight tracks, and for model generation and perspective display. The demonstration display program simulated an octagonal tower and had 360° coverage in the software, though the displayed data for the demonstration covered three windows of the cab only.

DML reports (reference 26, pp. 1-2) that "... the consensus of many observers of the display has been that the quality of the representation of the view is good and that an aircraft and landscape provided in this manner is realistic, adequate for training purposes, and has considerable potential...." Projection of the scene by TV camera resulted in some degradation, but the quality of the overall view was considered "realistic for the proposed purpose."

A video tape showing the demonstration display of the DC9 image and flight characteristics was presented at NAFEC. The general response was that the image quality needed refinement, but the general concept had potential.

GENERAL ELECTRIC (GE) TOWER SIMULATION CONCEPTS (TOWER CAB, PANORAMIC SCREEN, CGI).

A simulation facility for tower training which includes the capabilities of CGI technology and employs the realism of full-scale cab and panoramic field of view has been conceptualized by General Electric Company's Ground Systems

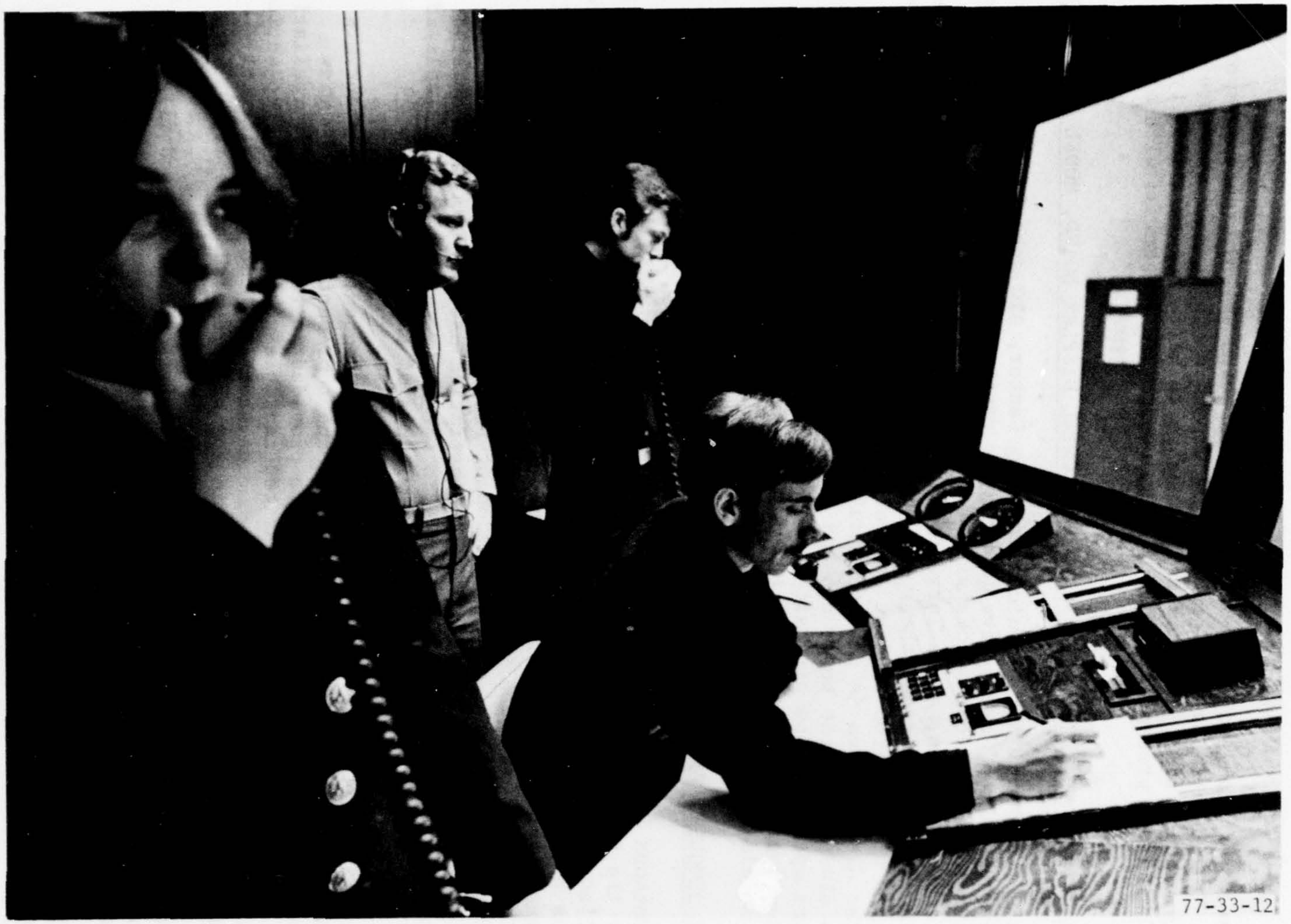
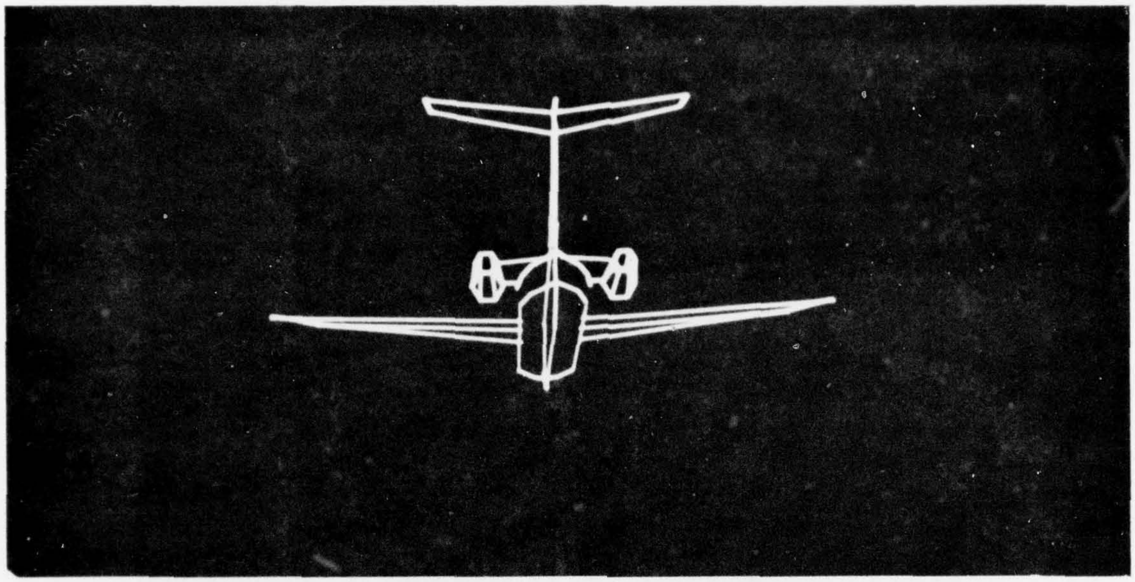


FIGURE C-7. STUDENT PILOTS IN USN TOWER SIMULATION TRAINING

FIGURE C-8. VIEW OF THE USN HORIZONTAL DISPLAY BOARD SHOWING PSEUDO-PILOTS IN FOREGROUND AND TOWER CONTROLLERS IN BACKGROUND



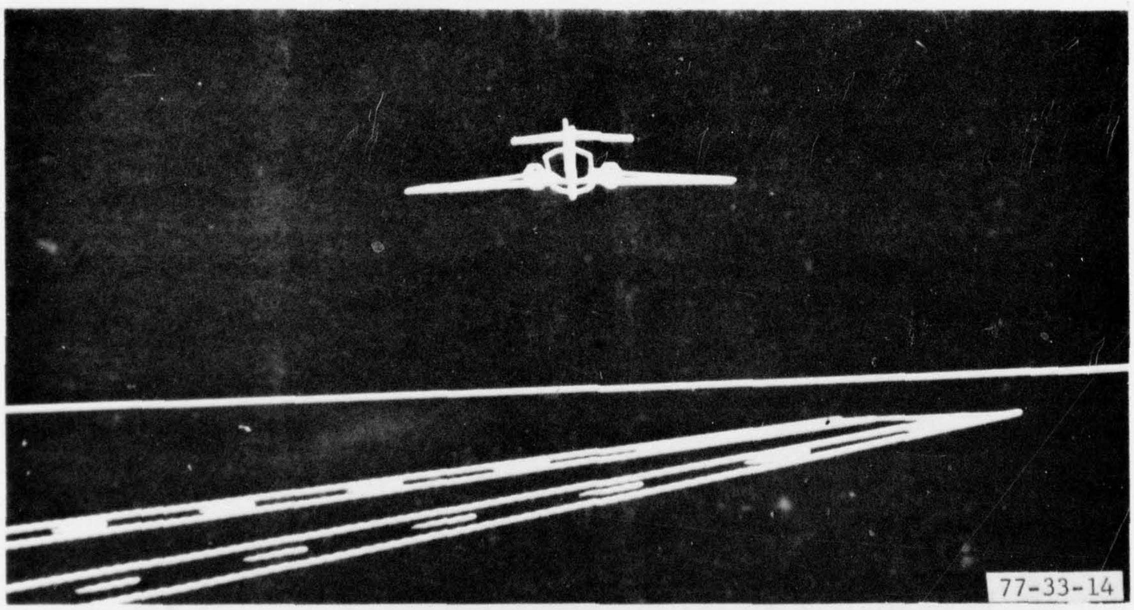


FIGURE C-9. VECTOR LINE DRAWING FROM DML TOWER SIMULATOR DEMONSTRATION MODEL

Department, and Video Display and Equipment Operations Department. Figures C-10, C-11, and C-12 show three concept drawings of various tower configurations. All use CGI, raster-scan, light-valve projection systems. Figure C-10 shows the four projectors situated on top of the tower cab, figure C-11 shows a similar system utilizing back projection, and figure C-12 represents a configuration employing "folded" optics which cut the projector throw distance.

The light-valve projector is described and evaluated in appendix B. It provides good visual realism and has the flexibility associated with digitally based environment depiction (e.g., simple modification, variety of environments).

CANADIAN AIRPORT TRAINER (CRT RADAR-TYPE DISPLAY, AIRPORT PLAN VIEW ALPHANUMERICS).

The following description of the Canadian system is based on a review of draft document "System Operational Requirements" and on conversations with personnel of Transport Canada. One system is presently in use at Air Transport of Canada Training Institute. Plans call for phasing in 2 to 5 more over a period of time. The simulator, using a digital computer, provides a real-time, plan-view display of targets for training air traffic controllers in both airport traffic control (as performed from a control tower) and terminal radar control.

The processor consists of a PDP-11/20 computer, disk storage, four keyboards, ASR-33 teletype console terminal, and floppy diskette package. The pilot position is equipped with a special-purpose keyboard and a 19-inch CRT tabular display. Each of four "pilot" positions can control up to 20 aircraft. The airport control position (equivalent to local control in the United States) is equipped with a 26-inch CRT normally set to a 16-nautical mile (nmi) range. It displays an airport map with runways, visual reporting points, rivers, etc., and target symbols representing various classes of aircraft. This position is also equipped with communications (six radiofrequencies, three hot lines, and interphones), wind indicators, altimeter setting indicator, runway light panel, airport lighting layout, light gun, crash bell, direction finder (DF) readout and runway visual range (RVR) readout. Figures C-13 and C-14 show views of the tower control position, the "pilot's" display, and the instructor's console.

The ground control position is equipped with a 19-inch CRT monitor displaying the same data as the airport control position (but able to show a different range), wind indicator, and altimeter setting indicator. Clearance delivery and flight data positions are provided, as well as two radar positions and a radar data position. The instructor-monitor position has the capability to monitor the exercise, control ATC equipment (wind, altimeter, RVR, etc.), create situations, record comments, record, and play back the audio and video data with the capability to record and play back simultaneously.

The system is expandable to provide for seven positions each of airport control, data control, ground control, and clearance delivery, and six radar positions (three pairs) and three radar data positions. It will also provide for additional instructor-monitor positions and, eventually, for precision approach radar (PAR) simulation.

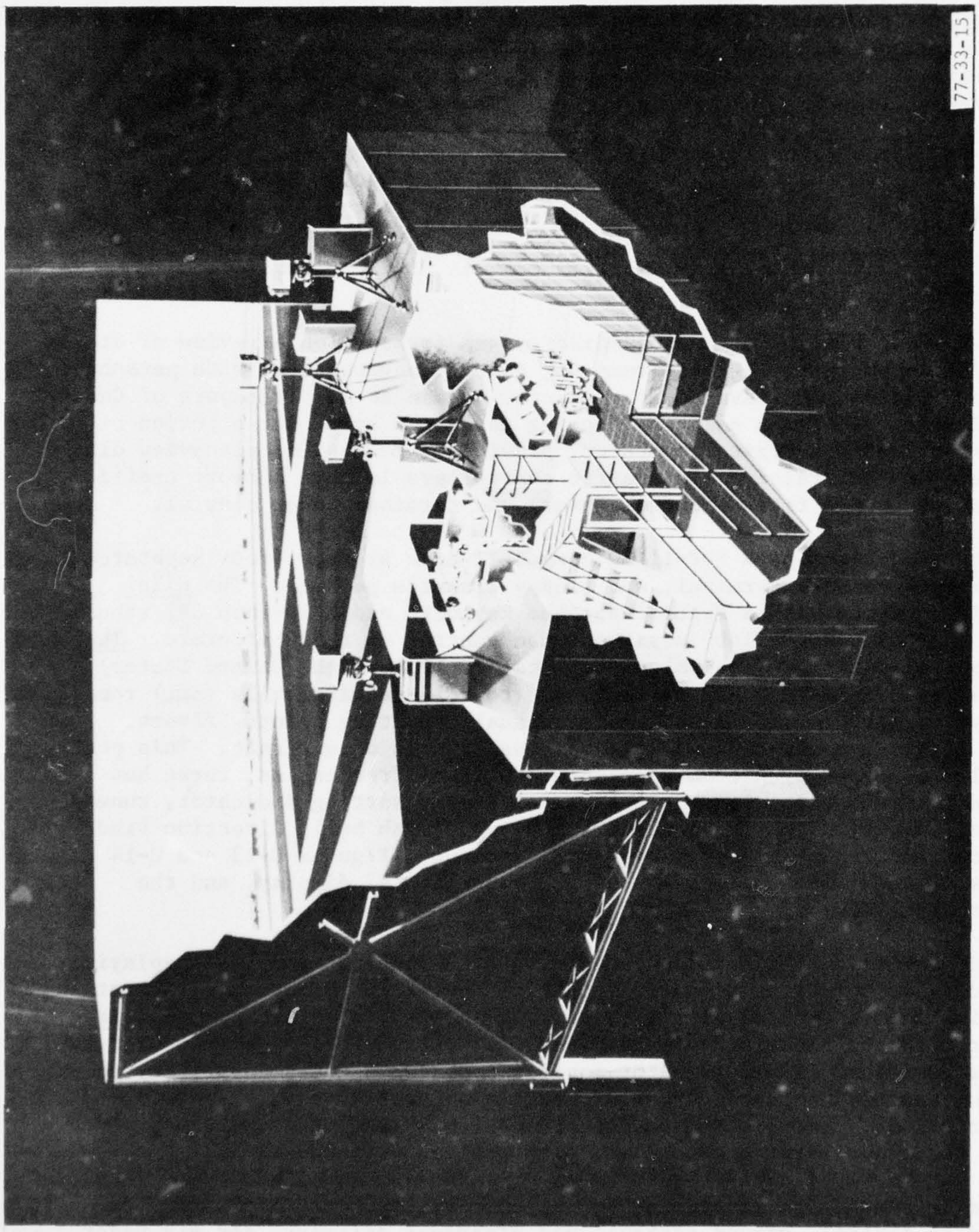


FIGURE C-10. GE TOWER SIMULATION CONCEPT DRAWING--FRONT PROJECTION USING LIGHT-VALVE

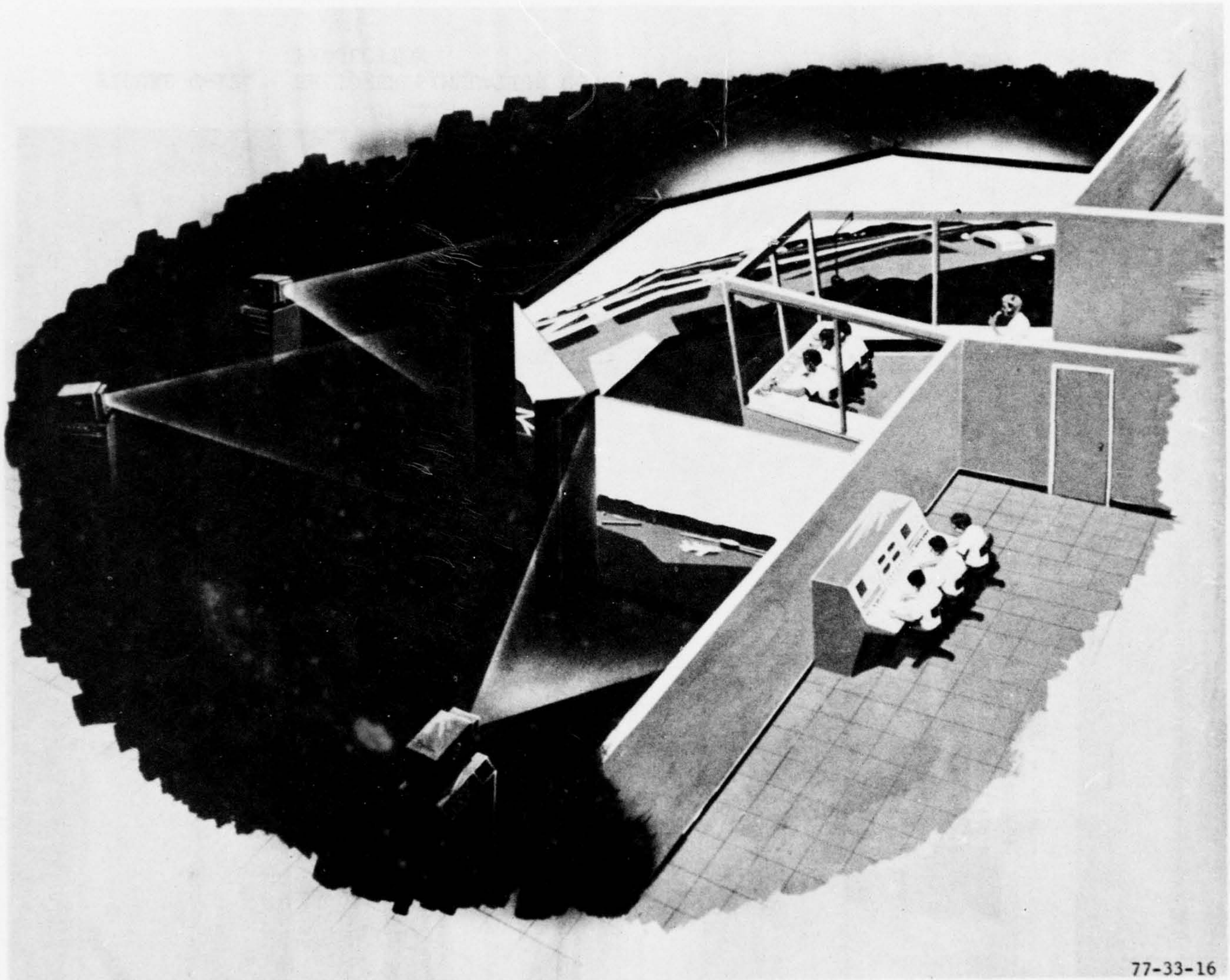


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FIGURE C-11. GE TOWER SIMULATION CONCEPT DRAWING--BACK PROJECTION USING LIGHT-VALVE

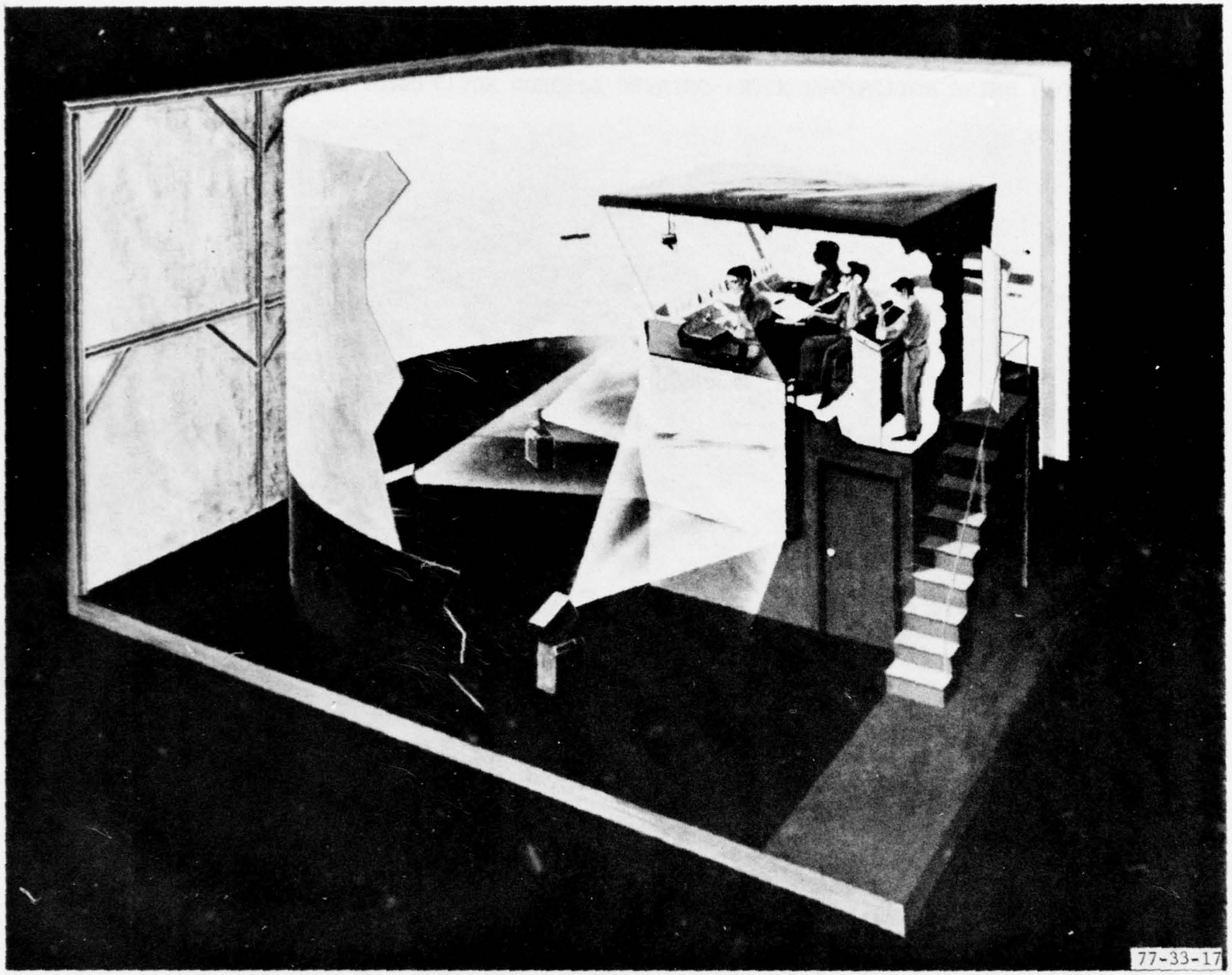
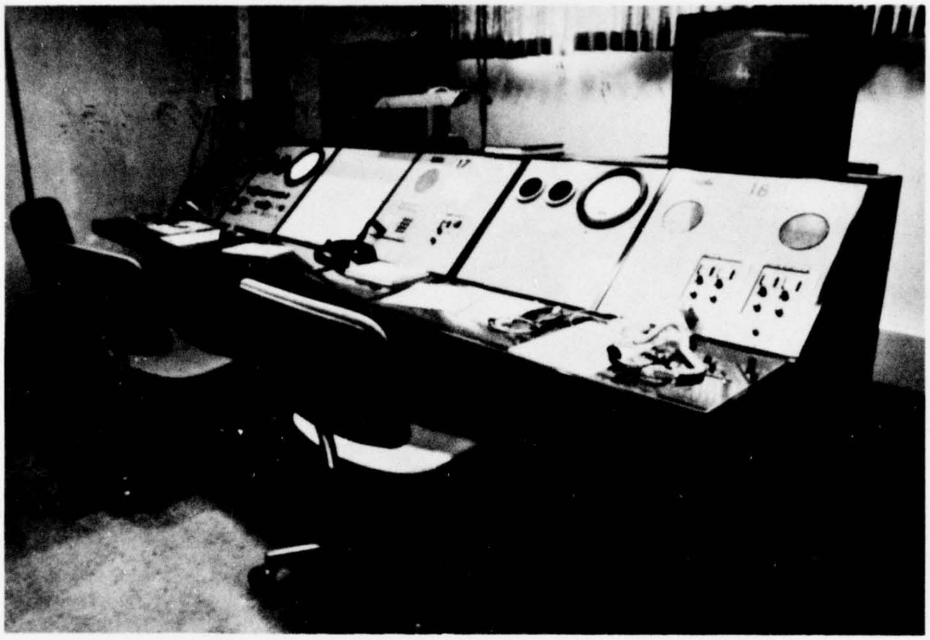
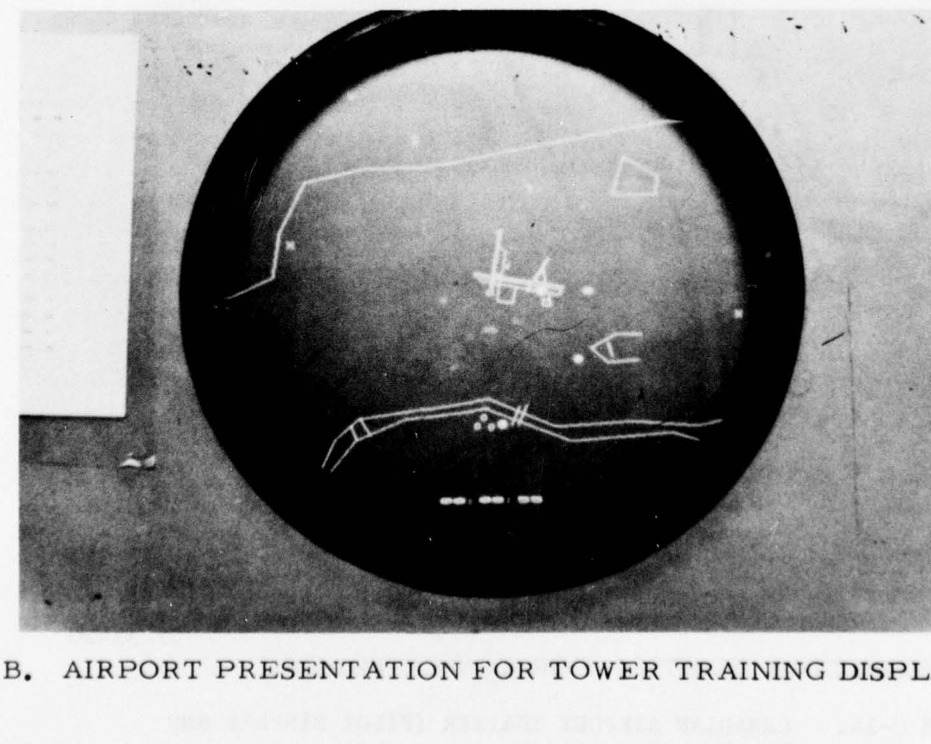


FIGURE C-12. GE TOWER SIMULATION CONCEPT DRAWING--"FOLDED" OPTICS, LIGHT-VALVE PROJECTION



TOWER POSITION SIMULATION



B. AIRPORT PRESENTATION FOR TOWER TRAINING DISPLAY

77-33-19

FIGURE C-13. CANADIAN AIRPORT TRAINER (TOWER CONSOLE AND DISPLAY)

A. PSEUDOPILOT'S DISPLAY

77-33-20

B. INSTRUCTOR POSITION FOR TOWER TRAININ

FIGURE C-14. CANADIAN AIRPORT TRAINER (PILOT DISPLAY AND INSTRUCTOR CONSOLE)

This appears to be a well thoughtout simulator that is capable of providing valuable training for a large number of students at what is probably a reasonable cost since it utilizes technologies that are well within the state-of-the-art, and equipment that is largely off-the-shelf.

Aside from the consideration of whether an out-the-window view is necessary, the only reservation felt was that in a high-density terminal situation it might be difficult for a pilot to make his keyboard entries as quickly as might be required. Experience in simulation indicates that in radar training, two to three pilots are usually required to handle one controller's traffic. The only means to decrease this ratio is either to reduce the amount of traffic, or to simplify or automate the data entries. While the keyboard described for this system is a special-purpose one, it does not appear to be simplified. There is little experience in tower cab simulation for guidance, but it would be encouraging to think that the Canadian system is flexible enough to allow for more than four pilot positions in case the pilot workload proves it to be necessary.

NAFEC TOWER SIMULATION MODEL (CRT DISPLAY, PLAN VIEW OR OUT-THE-WINDOW VIEW).

NAFEC has demonstrated a method of accomplishing VFR tower training by displaying simulated radar targets on CRT displays. The Digital Simulation Facility (DSF) was used to display and control targets taxiing, arriving, landing, taking off, departing, and flying in the traffic pattern. Plan views of an airport area at 6-nmi and 1.5-nmi radius range from the tower, respectively, are shown in figures C-15 and C-16. Figure C-17 represents a view from a tower window. The report of the demonstration (reference 27) explores the feasibility of this method compared to a visual scene simulation facility and concludes that this method may be able to accomplish all or most of the preliminary tower training. The report states that "the same cues are provided to the deciding and learning mental process" by a plan view presentation. However, there is no supporting evidence for this statement. It is not known to what extent visual cues are utilized by tower controllers in the decision-making process. This is a topic of much current interest and was discussed at a recent conference on CGI technology for visual scene simulation (reference 28). The consensus was that research is needed in order to specify the type, role, and importance of visual cues in simulation, training, and performance. Pilots, at one time, marked their windows with a grease-pencil to help "line-up" visual information. Control tower operators are also known to utilize the relative locations of visual information (e.g., an aircraft at a certain position in the tower window frame and of a certain size, as seen from a particular viewing position) in order to make control decisions.

One problem encountered in the NAFEC demonstrations was the inability of the pilot to enter certain airport traffic control instructions, because the DSF pilot keyboard is designed primarily for use in a radar control environment. This problem was handled for the demonstration by having an "interpreter" convert the airport traffic control instructions into appropriate radar terms for the pilot. This experience generated a recommendation that a pilot device be developed for use in the Radar Training Facility (RTF) scheduled for installation at the academy that would enable pilot entries of both control tower and radar instructions.

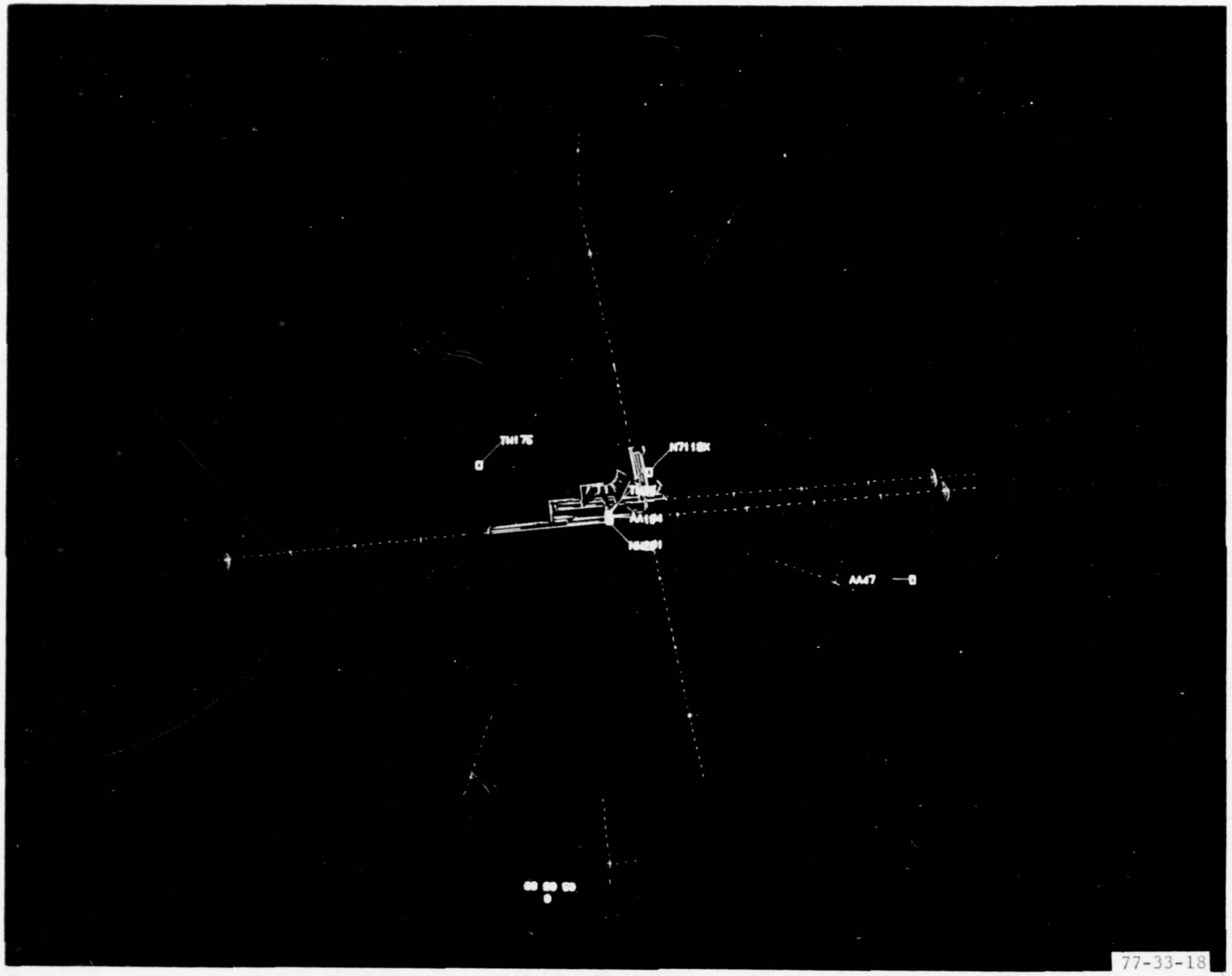


FIGURE C-15. NAFEC TOWER SIMULATION MODEL--6-NMI RADIUS PLAN VIEW

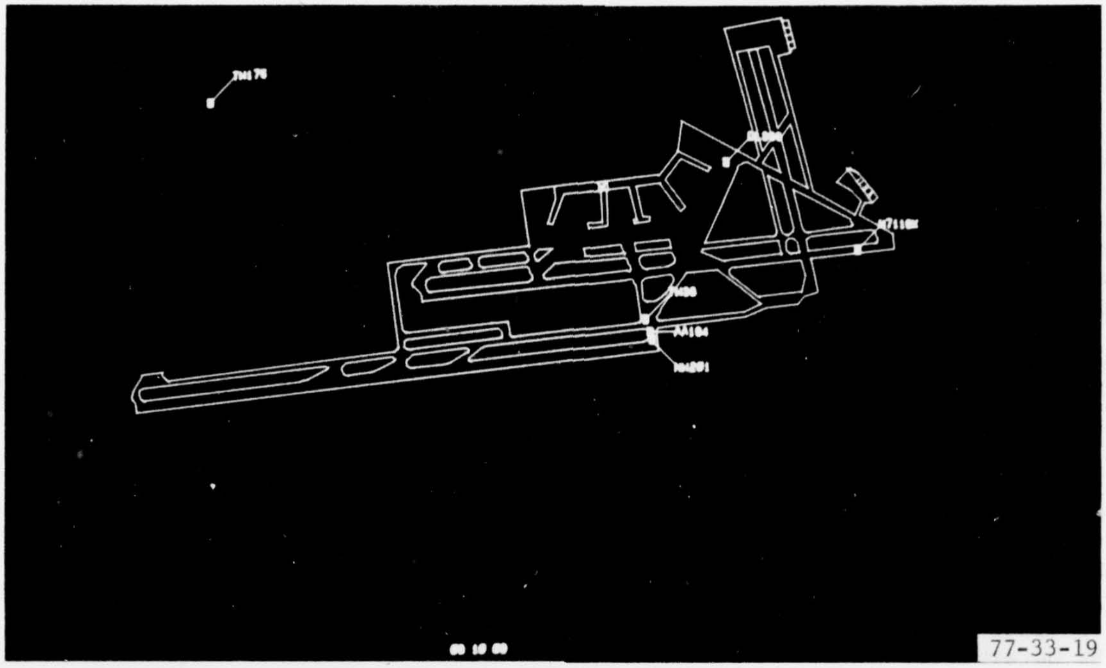


FIGURE C-16. NAFEC TOWER *SIMULATION MODEL*--1.5-NMI RADIUS PLAN VIEW

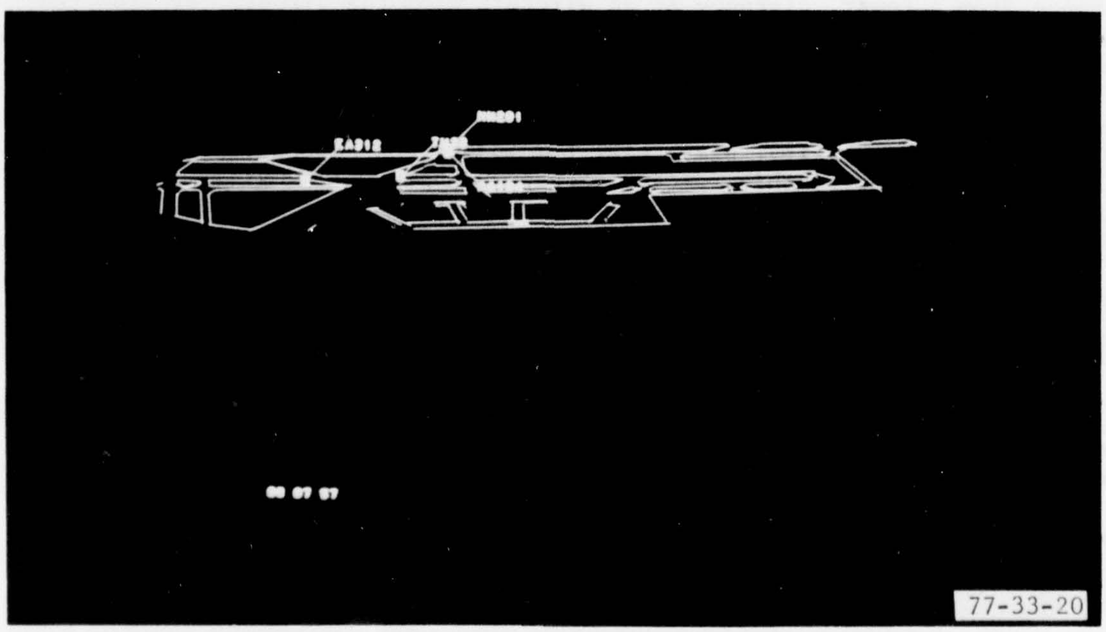


FIGURE C-17. NAFEC TOWER SIMULATION MODEL--PERSPECTIVE FROM TOWER CAB WINDOWS

The NAFEC tower training demonstration is markedly similar in concept to the Canadian system. Both of the recommendations contained in the NAFEC letter report (i.e., tower and radar training capability in a single system, and pilot keyboard capability of responding to both kinds of instruction) appear to have been carried out in the Canadian system with the exception that the Canadian system uses a keyboard as a data entry device; whereas, a touch-entry device was recommended in the NAFEC system.

Arguments regarding use of a simulated radar display versus using a simulated visual scene apply equally to the NAFEC and Canadian systems. If it is remembered that training for local control and ground control has historically consisted of classroom work followed by on-the-job training (with sporadic use of model airplanes carried around a plywood landing field) then simulation using radar targets does appear to be a progressive step forward. The use of this method undoubtedly can provide a good deal of the training that is needed and can nicely fill the existing gap between classroom and on-the-job training. The significance of the lack of realism attainable using this method, and whether or not it is "worth it" to provide an airport visual scene, remain to be determined.

Simulation of local control by use of a radar-type display will suffer to an unknown extent, because of several factors related to perception and perspective such as the following: Spatial relationships from a tower cab are radically different from the "plan view" provided by a radar display. Distance from a tower, distance of an aircraft from the airport, or from the runway threshold must be judged. A radar display makes this distance explicit, rather than requiring the learning of the judgment. These judgments cannot be taught with a radar display, and some "unlearning" may have to be accomplished later during on-the-job training. Distance, as observed from a tower cab, affects detectability, size, clarity, color, and detail of an aircraft. Radar would not provide this, except perhaps symbolically. Visibility from a tower cab may vary with the quadrant, or with height, or with distance. Radar might provide this, but only in a symbolic way.

Despite the above limitations, it is felt that a radar presentation can accomplish important and valuable training in traffic pattern management and in using and hearing phraseology appropriate to the tower cab.

No particular technical or maintenance problems need be anticipated. All equipment can be essentially off-the-shelf items with standard electronics. Training of maintenance personnel would be at a minimum and their ability to maintain minimum downtime should be the best of any system examined. Replacement parts at reasonable expense should be readily available.

APPENDIX D

SHIP'S BRIDGE SIMULATORS

CAORF (Computer Aided Operations Research Facility)

Marine Safety International's Ship's Bridge Simulator

CAORF: U.S. MARITIME SIMULATOR (SHIP'S BRIDGE, PANORAMIC SCREEN, AND CGI).

The Computer Aided Operations Research Facility (CAORF) is a sophisticated simulation system using CGI techniques. CAORF was developed by Sperry Rand Corporation for the Maritime Administration, and is located at the United States Merchant Marine Academy, Kings Point, New York. The $12 million facility, inclusive of building, represents the research and development efforts of a number of companies including Grumman, Northrup, and GE for simulation, automation, and communication support, and Evans & Sutherland for image generation software.

CAORF uses a full-scale bridge mockup fitted with contemporary bridge controls and computerized equipment to simulate a wide range of navigational traffic situations and environmental conditions. The facility is intended for research use, particularly with regard to human factors problems in navigational operations rather than as a training facility. An artist's drawing of the facility is shown in figure D-1, and a functional sketch of the system's operations is given in figure D-2. A view through the bridge windows is shown in figure D-3. It provides a full-color, detailed view of a shoreline including buildings and geographic markings of a port or harbor on a panoramic screen, 15 feet by 125 feet, with a radius of 24 feet from the "preferred viewing point" on the bridge. Field of view is 240° in azimuth and 24° elevation. Figure D-4 gives the floor plan and an elevation drawing of the bridge and screen areas.

As the ship's course or speed is changed, the visual scene is altered accordingly, resulting in an illusion of being on the bridge of a moving vessel. Up to six controllable moving vessels can be displayed in the visual scene at the same time. These ships can be maneuvered in a realistic manner within the visual area. Any level of light, from daylight to night, and any degree of fog or haze can be created by the image generator. The pictures in figure D-5 show scenes from the bridge in various levels of fog conditions.

The basic components of the simulator are:

The bridge which contains steering and propulsion controls and displays, radar indicators, collision avoidance system displays, and a variety of communications systems. The bridge itself is built on a raised platform for ease of cabling and bridge layout rearrangements.

The central data processor, the "heart" of the system, responds to steering and propulsion commands from the bridge, and controls three other computers: the image generator, the radar signal generator, and the control station. The central data processor permits playback of any part of a past voyage.

The image generator and display. Five Eidophor projectors mounted above the wheelhouse project a computer-generated scene on a screen which can be seen through the wheelhouse windows.

The radar signal generator produces video on the radar indicators. The video is correlated with the visual scene on the screen. Topographical features (shoreline and buoys) and up to 40 moving ships can be displayed.

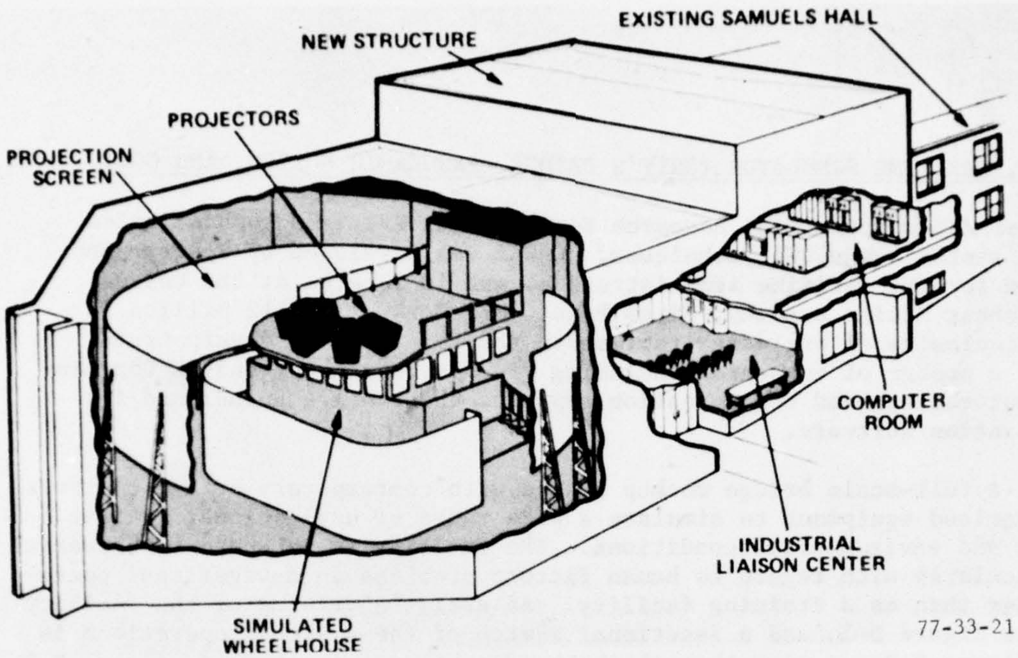


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FIGURE D-1. ARTIST'S DRAWING OF CAORF FACILITY

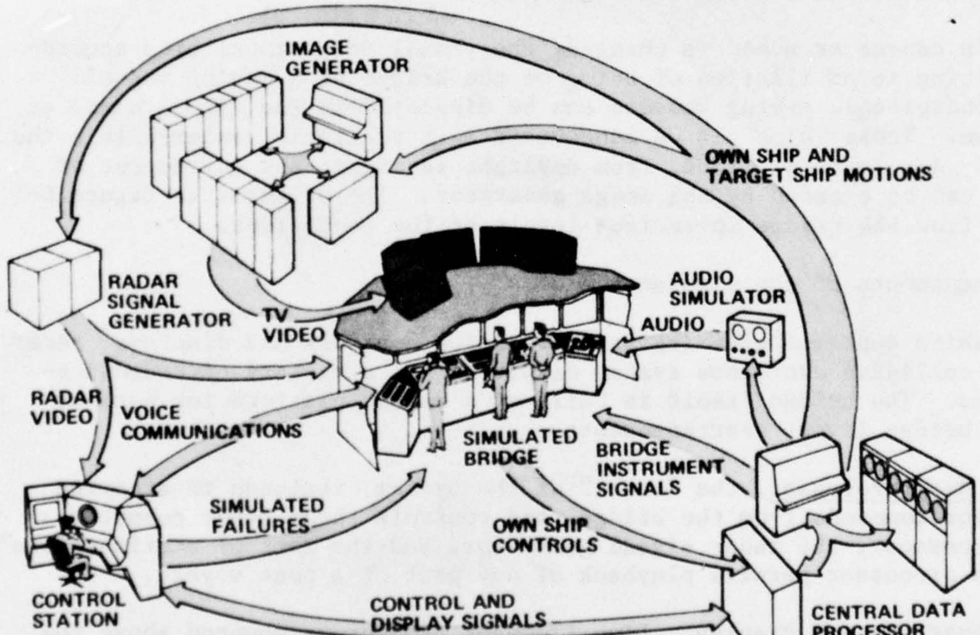

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FIGURE D-2. CAORF OPERATIONAL FUNCTIONS

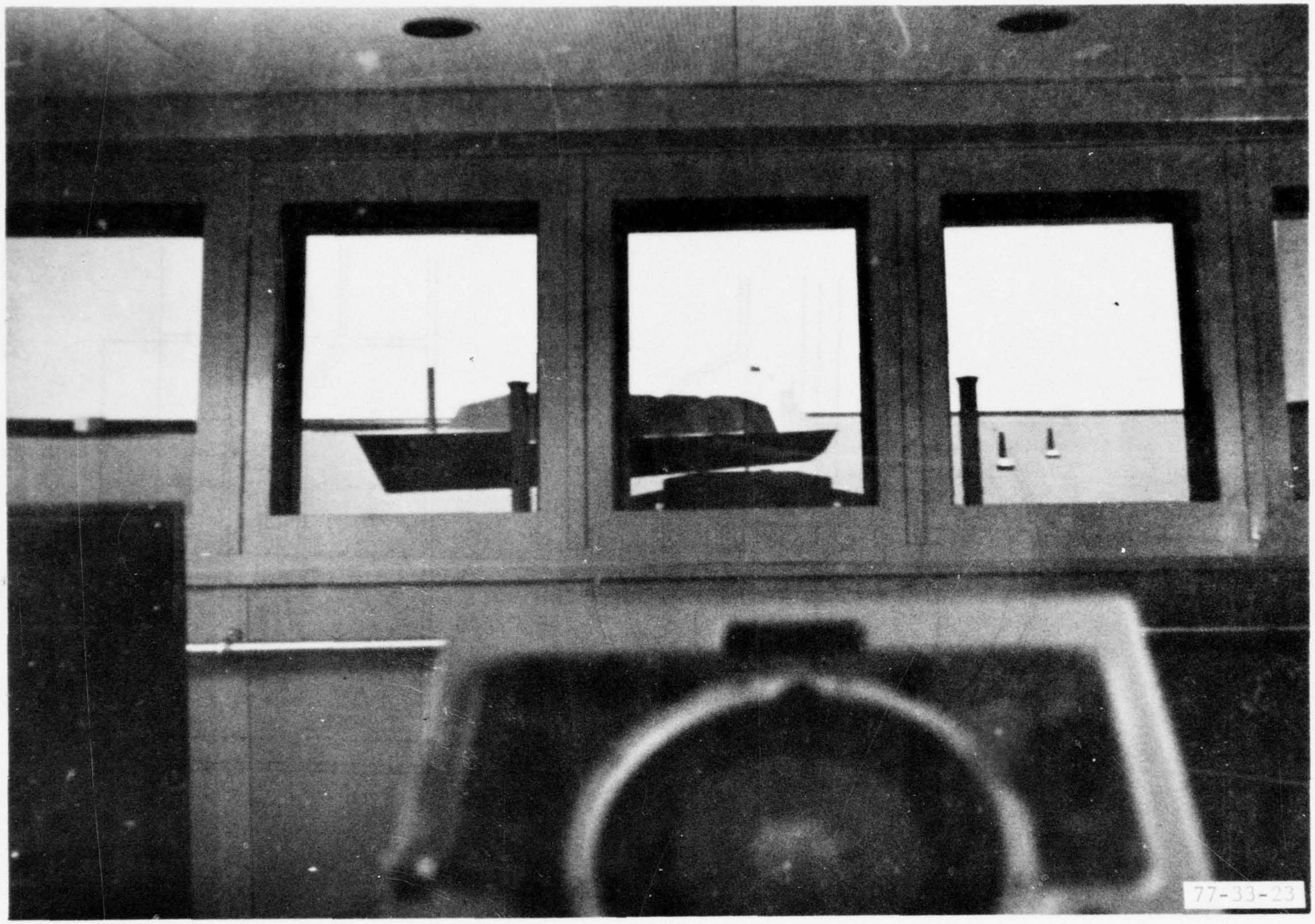


FIGURE D-3. CAORF SCENE THROUGH SHIP'S BRIDGE WINDOWS (PROJECTION IN FULL COLOR)

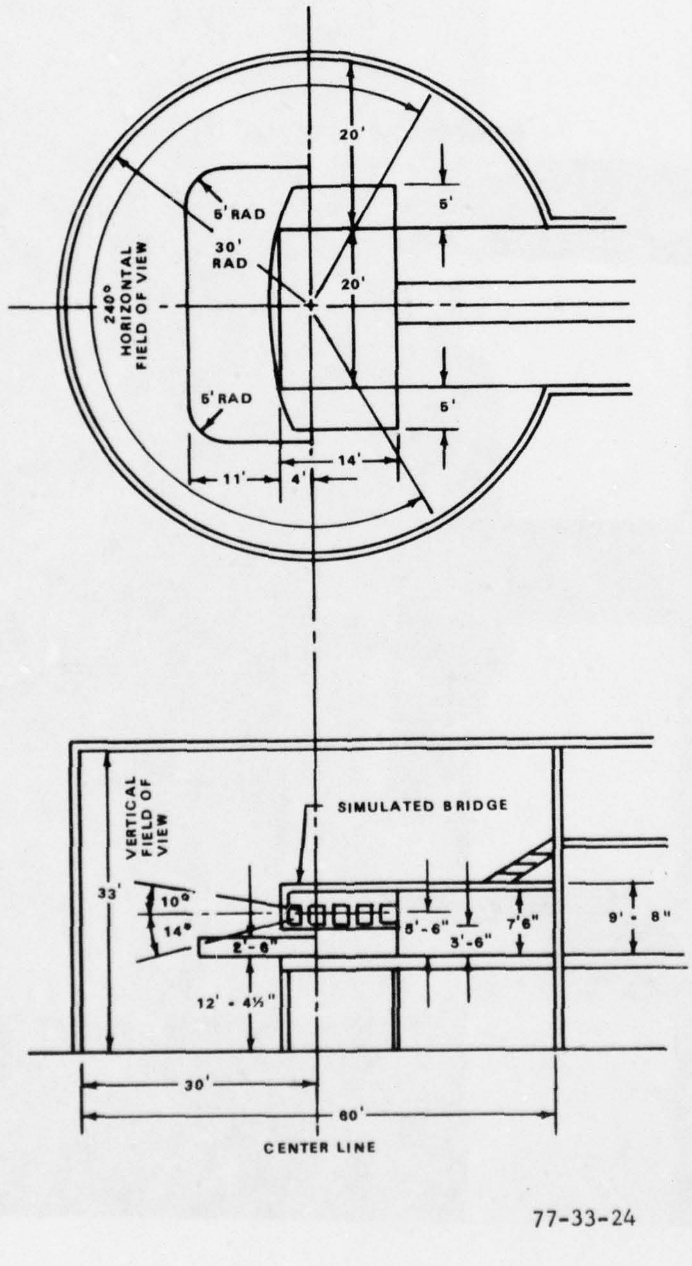


FIGURE D-4. CAORF FLOOR PLAN AND ELEVATION DRAWING

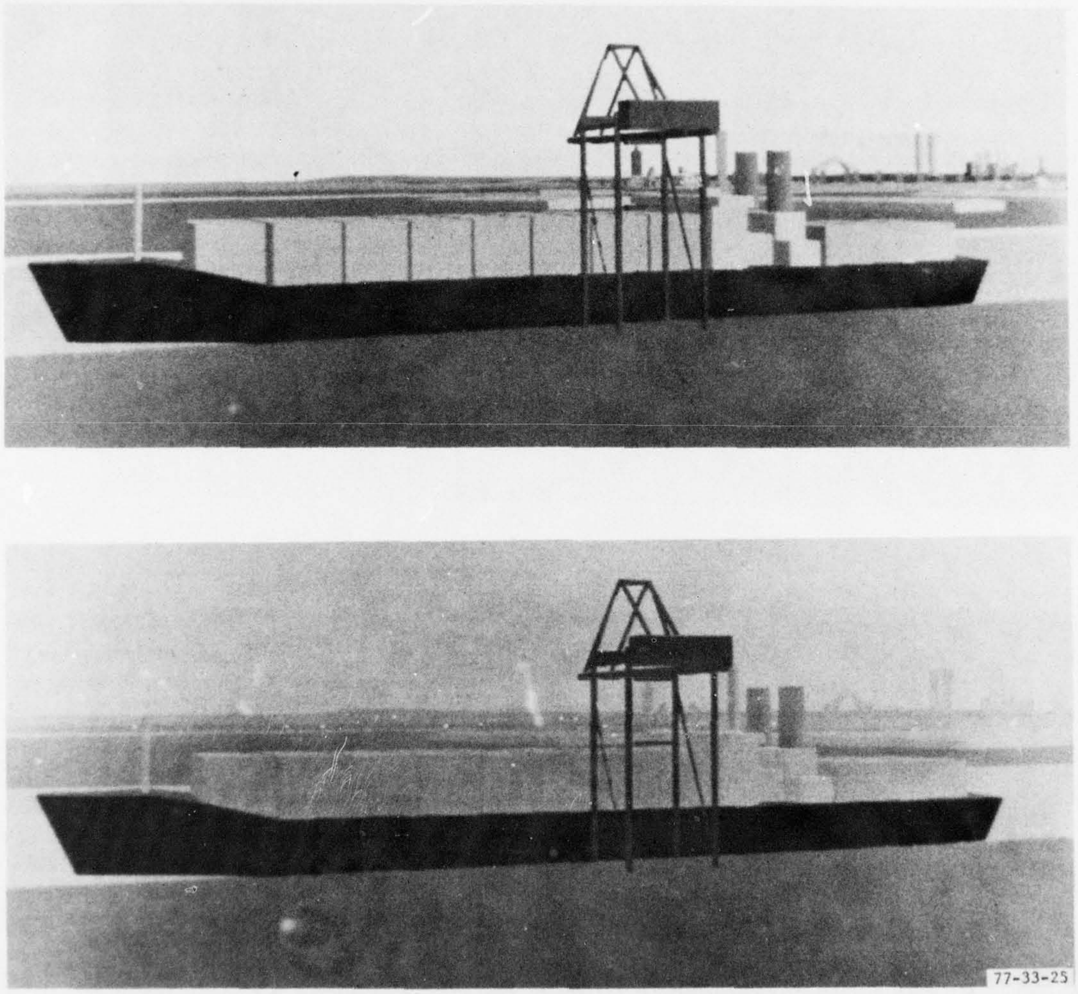


FIGURE D-5. CAORF-DEPICTED VIEWS FROM SHIP'S BRIDGE IN VARIOUS LEVELS OF FOG (SHEET 1 of 2)

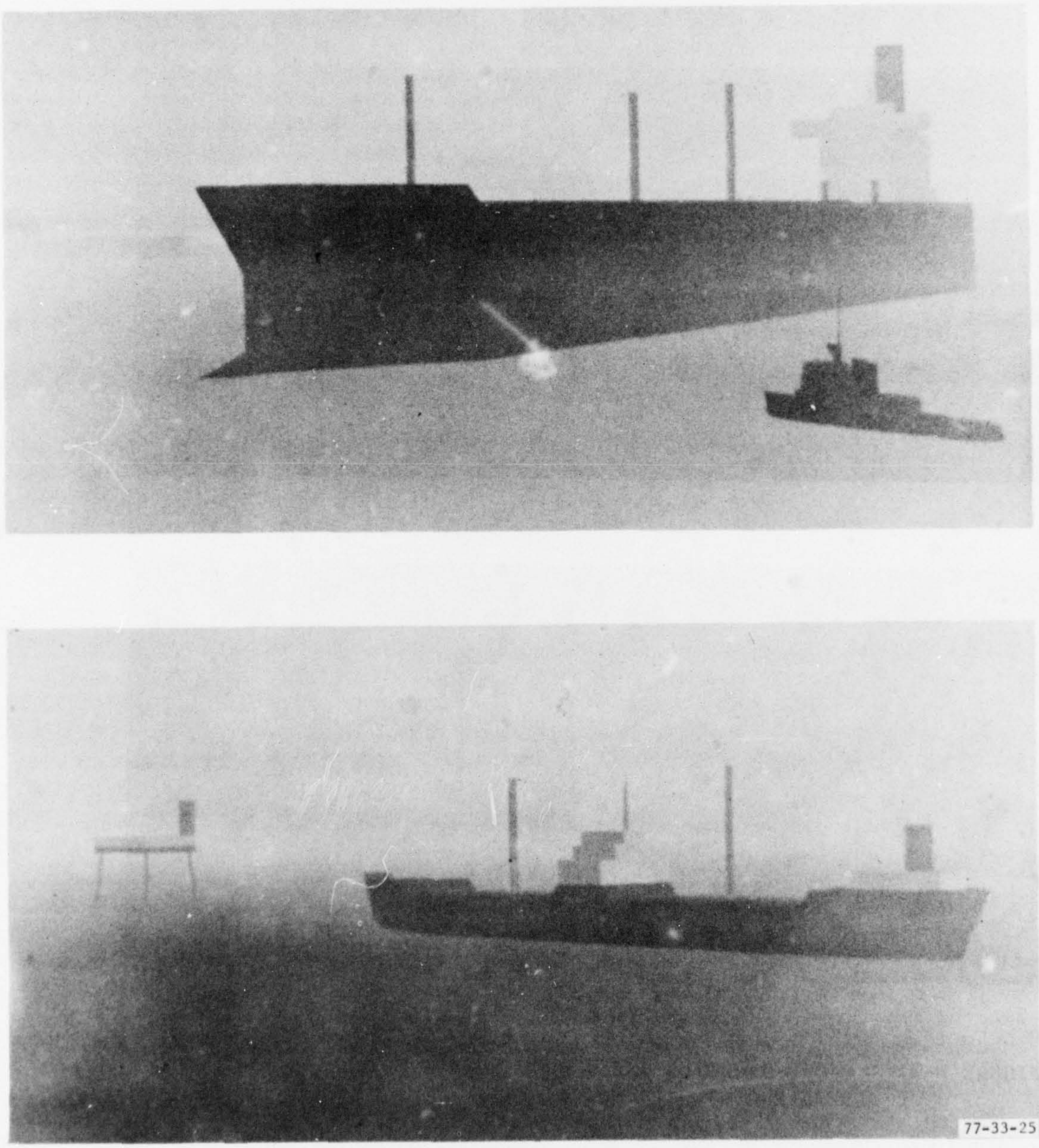


FIGURE D-5. CAORF-DEPICTED VIEWS FROM SHIP'S BRIDGE IN VARIOUS LEVELS OF FOG (SHEET 2 of 2)

At the control station the experiment is initiated, monitored, and directed. Personnel at this station also direct the courses and speeds of other vessels displayed on the screen and on the radars, simulate communications, and can also cause machinery malfunctions on "own ship," including loss of steering which could set up collision situations.

On the two visits made to CAORF by project personnel, computers were programmed to provide ship handling characteristics of an 80,000-ton tanker operating either in the open seas, New York harbor between Ambrose Tower and Port Newark, or in the waterways approaching Valdez, Alaska. Computer programs can be developed for any other ship type and any other port or area in the world.

On viewing the facility it is immediately apparent that by substituting a control tower cab for ship's bridge, an airport scene for the harbor environment, and aircraft images for the six "other" vessels, that a facility like CAORF could provide a powerful and realistic tower simulation capability. However, small images displayed on the CAORF screen (such as ships at a distance) seemed indistinct, and as the objects approached "own ship" there appeared to be quantum jumps in size and amount of detail. This is a function of the resolution and of the description detail in the data base. Software improvements are continually being made, and it was observed, by way of example, that suspension bridge cables which had appeared on the first visit as jagged lines, appeared as smooth lines on our second visit to the site. Also, more "edge" capability had been added, which provided for more objects in the scene.

Although the luminance of the display was relatively low, the use of color and contrast produced the effect of direct sunlight and brightness. Lighting within the bridge (or tower) area could be rather bright without affecting the image displayed as long as the interior light did not shine directly on the screen.

A special demonstration showed a hydrofoil at the farthest distance programmed for the system (approximatley 100 nmi) proceeding toward "own ship" and passing by it at high speed. The idea was to create the effect of an aircraft's speed and motion relative to a tower. One can assume that higher resolution would produce a smoothly "growing" image corresponding to range changes. Light-valve projection, in place of the Eidophor, using the newer 1,000-line resolution, would provide better detail and brightness. However, it was felt that the quality of images seen at CAORF would be acceptable for a tower simulator.

The disadvantages of such a facility are several. The area required to house the simulator and computers needs to be large. Such a facility would provide training for only one team (local, ground, clearance delivery, and flight data) at a time. While the great size, great cost, and small training capacity of CAORF would seem to eliminate it as a candidate for a tower simulator, some of the techniques utilized by CAORF could be applied successfully to airport tower simulation. A visual scene such as that generated for CAORF could be presented on a midsize system at considerably less cost (see appendix E, Instructor's Console for Flight Simulator).

The Eidophor projection system had been operationally and technically evaluated at NAFEC and was in operation at the JFK Airport Common IFR Room in New York. The NAFEC technical report (reference 25) describes the maintenance and reliability of the device. Initial expense of the Eidophor is high. It is foreign made, and no second source of parts exist. Replacement parts are expensive. The vacuum chamber, in which an electron gun is housed to provide a TV raster, is not hard enough to prevent a critical cathode failure. A cathode failure can be expected about every 75 hours. Three such cathodes are used sequentially, and after these fail, vacuum must be released, and the cathodes replaced. After 2,000 hours of operation the vacuum chamber must be overhauled. This overhaul cannot be readily accomplished in an operting location. Thus, it can be seen that maintenance of the Eidophor can be considered extraordinary. In order to obtain continuous operation it will be necessary to have backup projectors available. Although Eidophors are operationally acceptable, except for some minor problems in color matching between displays, they should not be considered for use for the above reasons unless other means prove unsuitable. The light-valve system discussed in appendix B is a good alternative.

The other parts of the CAORF system consist of standard electronics, and no serious deficiencies can be considered to exist. They can be considered to offer equally dependable service when compared to other systems.

MARINE SAFETY INTERNATIONAL SHIP'S BRIDGE SIMULATOR (PANORAMIC SCREEN, TV/MODEL BOARD).

This facility, located at the Marine Air Terminal, LaGuardia Airport, New York, is a ship's bridge pilot training simulator (figure D-6). The system was viewed in operation on a TV program. The visual scene depicted was powerfully realistic. It provides a wide range of own-ship dynamics, and a panoramic (140° by 24°) field of view of a 50-square-mile gaming area on a 12 by 60 foot Cinerama-type screen. Visual simulation is achieved through use of a three-camera, wide-angle optical probe maneuvered about a 15 by 30 foot (2,000:1) model of a geographical area. The probe sends its video signals to three Eidophor projectors below the wheelhouse which display the picture onto the screen. Cultural features such as ships, docks, and navigation aids, selectable levels of visibility (zero to ideal), selectable gaming area, auditory realism, bridge realism, and high brightness are some of the features provided.

Simulation is in real-time. Bridge commands are executed by a digital computer which provides inputs to all instruments and ensures that the perspective of the panorama reflects the changes of own-ship's position. The video signals are corrected for projection onto the curved screen and for above-and-below eye-level perspective accuracy. Operating modes include freeze, record, and playback. Prior to running a training exercise, initial parameters related to own-ship, wind current, and preprogrammed malfunctions are inserted into the simulator system. A limited number of "other" ships can be made available on the display.

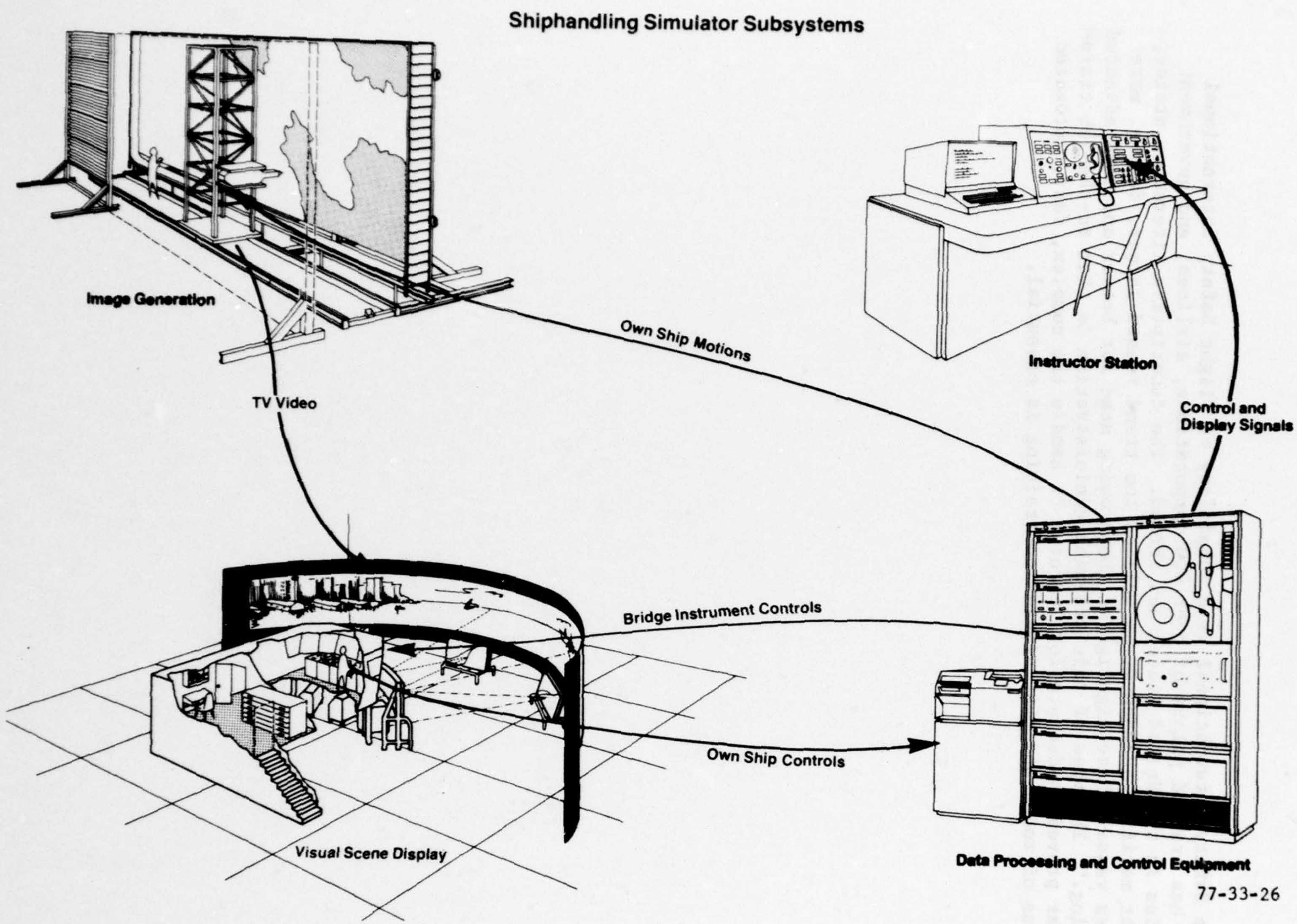


FIGURE D-6. MARINE SAFETY INTERNATIONAL SHIP'S BRIDGE SIMULATOR SUBSYSTEM

Marine Safety International is a subsidiary of Flight Safety International which has trained pilots of over 800 corporations, airlines, and government agencies in the United States and abroad. The descriptive literature states, "Recent maritime accidents, as well as the trend toward larger, faster, more complex vessels have highlighted the growing need for better and more advanced training." The view of this training administration is that on-the-job training has proved inadequate for learning to handle the complex, fast, automated systems of today and that simulation training is essential.

APPENDIX E

FLIGHT SIMULATORS

USAF Wide Angle Visual Flight Simulator

Multiple Flight Simulator

Instructor's Console for Flight Simulator

FLIGHT SIMULATORS

WIDE-ANGLE VISUAL FLIGHT SIMULATOR (USAF ADVANCED SIMULATION FOR PILOT TRAINING (ASPT)).

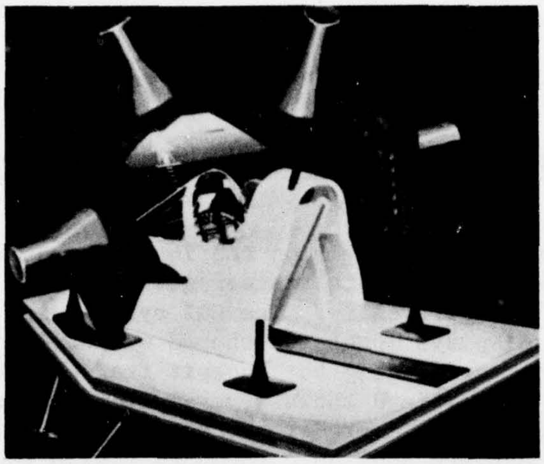
Built by General Electric Space Division and installed at Williams Air Force Base, Arizona, this is a T37 cockpit trainer giving a very wide field of view, 240° horizontally by 180° vertically. The CGI system uses seven black-and-white television tube displays (pentagon-shaped windows) configured as seven sides of a dodecahedron surrounding the cockpit trainer. Figure E-1A gives a view of the simulator cockpit and shows several of the pentagon windows. A computer-generated image of an intruder aircraft is shown in figure E-1B. Edge-smoothing techniques are available to do away with the stair-step effect along the lower edge of the image.

This facility provides a high degree of realism for flight training where much of the task learning is eye-hand coordination in response to changes in the visual scene depicted. Resolution is adequate for this purpose, but should probably be higher for a tower simulation where a large number of aircraft and/or ground vehicles would be portrayed and aircraft identification, perhaps, a requirement. To have color would bring the cost up considerably. Also, to enlarge the area to resemble a tower configuration would be costly due to the size of the CRT's and optics required.

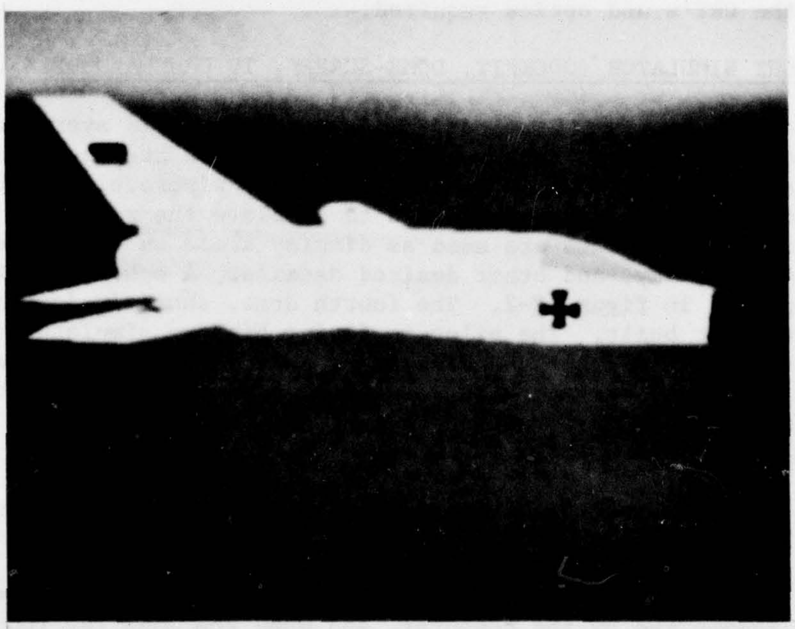
MULTIPLE FLIGHT SIMULATOR (COCKPIT, DOME-SCREEN, TV CAMERA/MODELS).

Built by McDonnell Douglas, St. Louis, Missouri, the basic system consists of three large domes in which fighter aircraft simulators are installed. These simulators have a cockpit layout similar to an F15 aircraft, though their flight characteristics can be controlled to simulate the responses of any fighter aircraft. The domes are used as display areas on which are shown details of terrain, sky, and other desired details. A schematic of the basic system is depicted in figure E-2. The fourth dome, shown in dotted lines, is planned but not yet built. The pilot in flying his own simulator is able to see the aircraft of the other two simulators depicted on his dome and his relative position and activity with respect to them. The pilots are interactively able to engage in formation flying, dog fights, landings, and other missions that are programmable.

The display generators are light-boxes housing aircraft models viewed by vidicons. The aircraft are models of the type of aircraft desired to be displayed. There are two of each model, mounted on gimbals, with one model mounted at the nose and the other at the tail. The viewing aspect of the vidicon to the model is maintained by the computer, and when the mounting rod interferes with the vidicon view of the model, the lights illuminating the model(s) are switched OFF and ON as needed. A light-splitter, made of a semimirror, enables the same vidicon to view both front- and rear-mounted models. The model in use is illuminated, and the other is not.



A. ADVANCED SIMULATOR PILOT TRAINER (ASPT)



B. AIRCRAFT IMAGE 77-33-29

FIGURE E-1. USAF ADVANCED SIMULATOR PILOT TRAINER SHOWING PENTAGON WINDOWS AND COMPUTER-GENERATED INTRUDER AIRCRAFT IMAGE

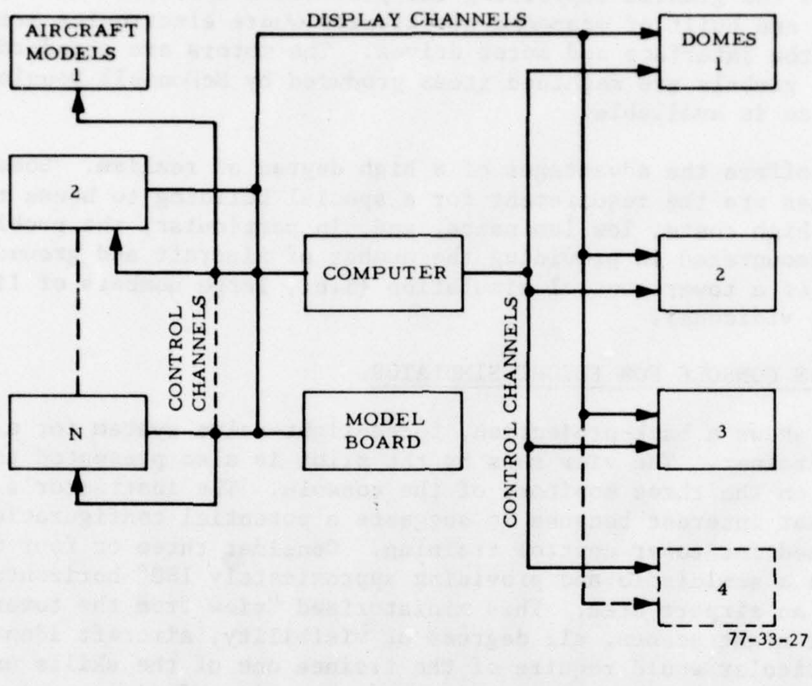


FIGURE E-2. BLOCK DIAGRAM OF THE McDONNELL DOUGLAS SYSTEM

In the domes, the image is reproduced on a CRT and is projected to the desired point under computer control by a Schmidt optical system. The CRT and projection system is also on a gimbal enabling the computer to point the projector. The apparent distance of an aircraft being viewed is computer controlled by shrinking or enlarging the television raster on the CRT. Background views (i.e., clouds and ground) are reproduced and displayed from either films or a model board.

The images reproduced are quite realistic, since they come from models. The flight characteristics of the various aircraft are stored in the computer and are called upon to control the reactions of the various aircraft being represented. The aircraft models, when used in conjunction with model boards, may be used in landing situations such as aboard aircraft carriers, landing strips, or in missions against land targets. The overall effect is one of extreme realism to the pilot or pilots involved. The low light levels of the projected displays do not equate to daylight scenes, but the use of color gives the effect of operating during the day.

The overall reliability of the system is quite high, since standard components are used. The exceptions to this are the light boxes containing the model aircraft and the gimbals supporting the projection systems. These, on the other hand, are built of standard electronics where electronics are needed, such as in the interface and motor drives. The motors are standard market items. The gimbals are machined items produced by McDonnell Douglas, and no second source is available.

The system offers the advantages of a high degree of realism. Some of the disadvantages are the requirement for a special building to house the system, relatively high costs, low luminance, and, in particular, the problems which would be encountered in providing the number of aircraft and ground images necessary for a tower control simulation (i.e., large numbers of light boxes, models, and vidicons).

INSTRUCTOR'S CONSOLE FOR FLIGHT SIMULATOR.

Figure E-3 shows a back-projection, three-light-valve system for a flight simulator trainer. The view seen by the pilot is also presented to the instructor on the three monitors of the console. The instructor's console is of particular interest because it suggests a potential configuration which could be used for tower control training. Consider three or four monitors arranged in a semicircle and providing approximately 180° horizontal field of view of an airport area. This miniaturized "view from the tower" could show day or night scenes, all degrees of visibility, aircraft identification, and in particular would require of the trainee one of the skills unique to tower control and that is the requirement that aircraft in a very wide field of view be observed and controlled (i.e., head movements would be necessary to see all aircraft in the area).

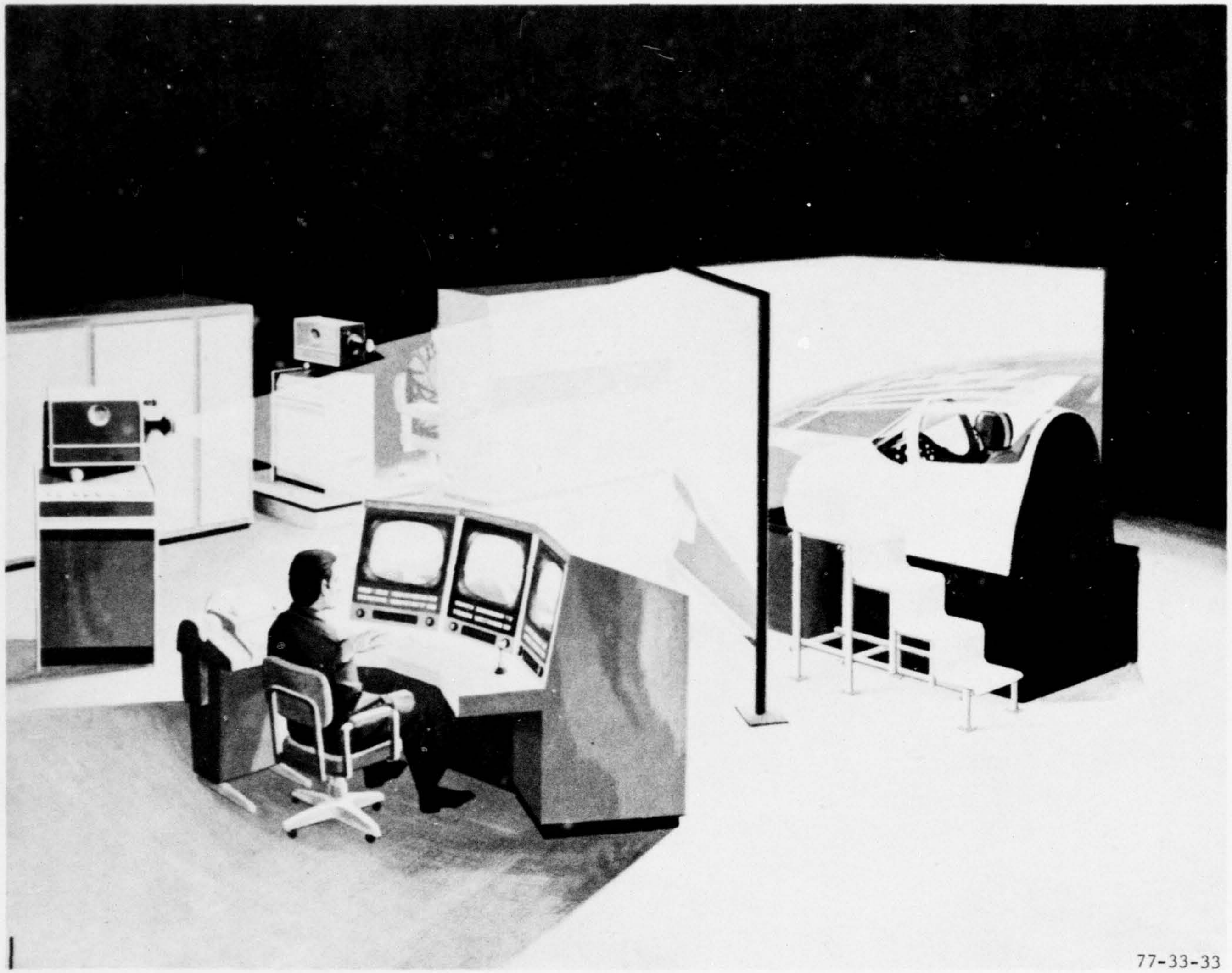


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FIGURE E-3. GE FLIGHT TRAINER AND INSTRUCTOR'S MONITOR CONSOLE

APPENDIX F

OTHER TRAINING TECHNOLOGIES

Picture System 2: An Interactive Graphics Display Console

Speech Understanding System (SUS) and Voice Generation Unit (VGU): An Automated Flight-Controller Trainer

OTHER TRAINING TECHNOLOGIES

PICTURE SYSTEM 2 GRAPHICS DISPLAY (CGI, CALLIGRAPHIC DISPLAY TERMINAL).

This is a sophisticated interactive computer graphics system. The descriptive literature by Evans & Sutherland, developers of the system, states, "Its image manipulation capabilities of translation, rotation, and scaling, combined with the ability to draw images in perspective, permits the building and dynamic display of flicker-free three dimensional models or pictures." The system uses the Summagraphics Data Tablet for general purpose graphic input and for operator interaction with the Picture System. The tablet and stylus are used in place of light-pens or joy sticks for pointing to picture "menu" elements. The X-Y coordinates of the stylus location are read by the system-controller (PDP-11) and appear as a cursor on the display.

One of the uses of the Picture System is shown in figure F-1, where a landing approach on the F16 Lightweight Fighter Aircraft Simulator is portrayed. At Evans & Sutherland, the Picture System has been used to develop aircraft and spacecraft models for eventual portrayal on their DAYNITE CGI system. Figure F-2 shows the calligraphic drawing of a space module on the Picture System, and figure F-3 shows the CGI protrayal. Other uses of the Picture System are in the design and display of turbine blades at Pratt Whitney and simulation of Short Takeoff and Landing (STOL) vehicle landing at NASA-AMES. At the New York Institute of Technology, the tablet and a color display allow the "painting" of animated color cartoons. This is a stand-alone system costing approximately $65,000. Its capabilities make it particularly attractive as a low-cost device for the development and dynamics display of instructional materials as well as an interactive terminal for student training.

SPEECH UNDERSTANDING SYSTEM (SUS) AND VOICE GENERATION UNIT (VGU): AN AUTOMATED FLIGHT CONTROLLER TRAINER.

Logicon, Inc., under contract with the Naval Training Equipment Center (NAVTRAEQUIPCEN) has been involved in the development of speech recognition technology applied to a controller training system (CTS) for ground-controlled approach (GCA) precision-approach training. The first system, delivered in November 1974, represented the first application of automated speech-recognition technology to a sophisticated training problem and the first attempt to apply automated syllabus control to the controller-type tasks. The system was first developed as a feasibility demonstration model particularly directed toward addressing the following issues: controller message understanding, objective performance measurement, and automated syllabus control. The VIP-100 speech-recognition system, designed and developed by Threshold Technology, Inc., was selected for the speech understanding subsystem (SUS). Modifications and enhancements to the SUS algorithms resulted in a task and vocabulary-independent FORTRAN callable software package. The GCA-CTS was evaluated at the Human Factors Laboratory at NAVTRAEQUIPCEN. An offline program was used to build a disk file of a 63-item (word or phrase) vocabulary, each item defined by expected duration of the utterance, a text code, a phonetic text sequence and a syntax structure which enables the concatenation of phrases.

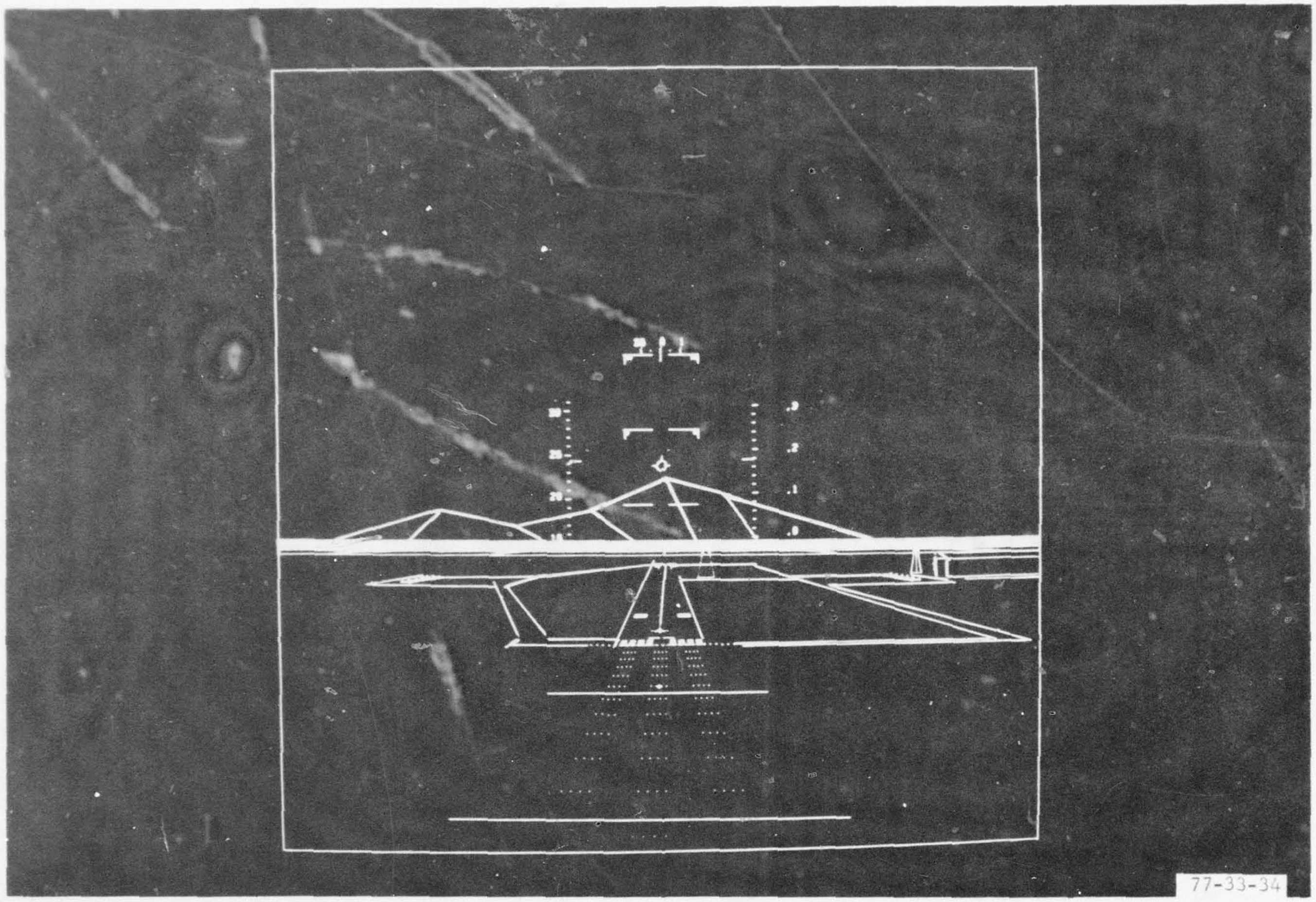

FIGURE F-1. PICTURE SYSTEM SHOWING LANDING APPROACH USING THE F16 LIGHTWEIGHT FIGHTER AIRCRAFT SIMULATOR

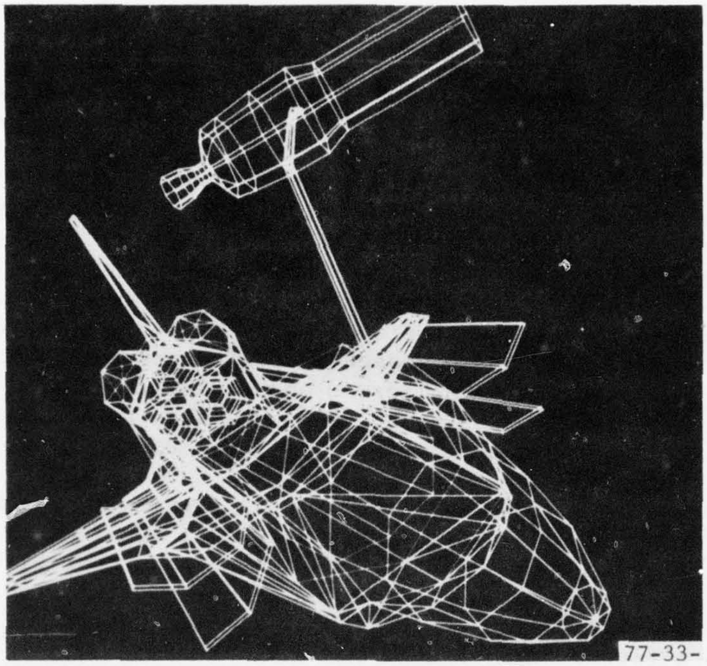

FIGURE F-2. CALLIGRAPHIC DISPLAY OF SPACECRAFT MODULE ON PICTURE SYSTEM

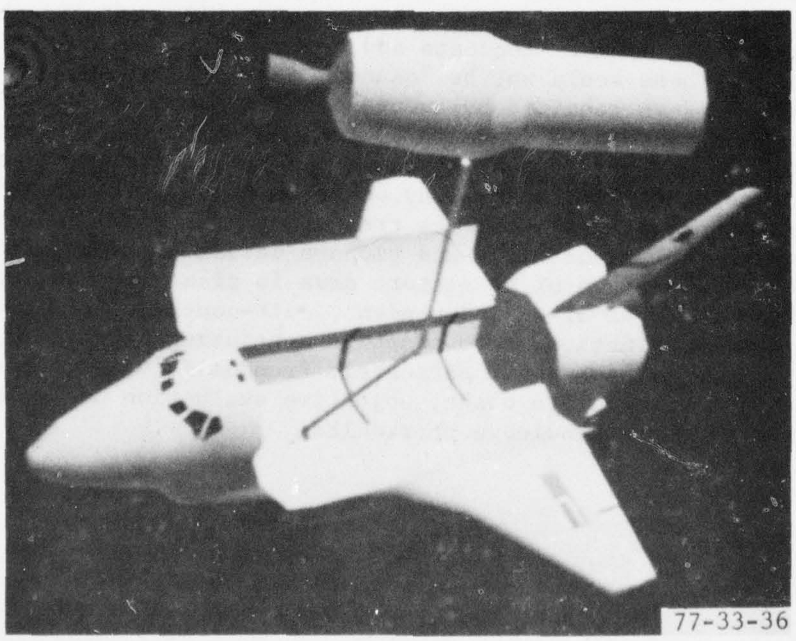

FIGURE F-3 COMPUTER-GENERATED IMAGE OF SPACECRAFT

The collection of user voice characteristics is accomplished by sequential presentations of multiphrase combinations, an improvement over early restrictions requiring a simple serial presentation of single items. Advantages are that the collection of voice characteristics can be done transparently (i.e., while the student practices phraseology) and with meaningful combinations of words. The program also provides immediate information as to the recognition accuracy of the SUS. Modifications can then be made to reduce the impact of the risk items. A report of the research can be found in references 29, 30, and 31. It should be noted that the system developed is a speech-understanding system, as contrasted with a speech-recognition system. Understanding utilizes contextual and other cues to improve and enhance the algorithms which function simply to recognize speech input. This operates to enlarge the potential vocabulary set and to increase accuracy of speech recognition.

One of the developments by Logicon as part of their continuing enhancements of automated flight training technology may have potential application to the FAA controller training needs. Whereas the precision-approach control vocabulary is limited in size and variability, that of the air-to-air intercept guidance controllers is more similar to the vocabulary of FAA controllers in that various heading and altitude changes must be given.

The capability of the SUS for handling more complex controller vocabularies coupled with high-resolution, high-speed computers and displays now available make the concept of a self-contained, self-paced training device entirely feasible. It would eliminate the need for pseudopilot support while providing complex dynamic ATC problems. Voice generation units (VGU) off-the-shelf can be programmed to provide "pilot" requests and responses in the controller training situation. These would not be "canned" messages per se, but would be statements generated as required by events occurring in real-time in the traffic problem. The display units used by Logicon in the flight-training systems (IMLAC CRT displays), Picture System 2 (described earlier in this section), as well as other similar display units on the market, provide bright images, high-resolution, and flicker-free presentation of graphical and alphanumeric information. The readability and picture detail are very good. The displays can provide a picture of an airport area in plan view, or out-the-window view. The advantages of an independent, self-contained trainer are numerous: self-paced instruction, more adaptive scheduling of training exercises, nondependence on pseudopilot support personnel, freedom for instructors to attend to non-routine instructive tasks, objective evaluation and measurement, and immediate and objective knowledge of results.